BASIC BIOLOGY

A Textbook for Secondary Schools

(Class IX)

PART ONE

Volume 2

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A Cactus in Bloom
(*Courtesy* Professor R.N. Kapil)

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UNIT III

LIFE PROCESSES

You have already learnt the characteristics of life (Unit I) These are uniformly expressed by specific activities performed through a series of biochemical reactions. Some of these life processes are nutrition, respiration, transport, excretion, coordination, reproduction and so on In fact, the maintenance of life depends upon an organism's ability to procure and utilize energy to perform these activities of life in a controlled and coordinated manner Though diverse forms of life appear to conduct these functions in different ways, there exists an intrinsic fundamental similarity amongst them. In this unit, you will study life processes so as to appreciate the 'unity in diversity', in the living forms, at molecular and biochemical levels

11

Foodstuffs

Carbohydrates, Fats, Proteins, Minerals, Vitamins, Water

LIVING ORGANISMS require food for the growth and maintenance of their body as well as to carry out various activities that characterize life How does the food enable them to perform different metabolic functions? Food, in whatever form it might be ingested, is eventually broken down in the cells to produce energy, carbon dioxide, water and other metabolic wastes It is this chemical energy that is basically utilized for the purpose of conducting various activities such as ingestion, digestion, absorption, respiration, movement, circulation, excretion and reproduction Food is also required to repair tissues and cells that wear out in the course of performing these functions and to build up resistance against disease as well

Types of Foodstuffs

The common human food comprises milk, milk products, fruits, vegetables, pulses, cereals, eggs, fish, mutton, pork, sugar, oil and ghee All these substances can be broadly classified into three categories carbohydrates, fats, and proteins. These are, of course, supplemented with minerals and vitamins in small quantities, and water

CARBOHYDRATES

Carbohydrates are compounds consisting of carbon, hydrogen and oxygen and have hydrogen and oxygen in the same ratio as in water (2:1) Hence the general formula of a carbohydrate is $C_n(H_2O)_n$ Some common sources of carbohydrates are rice, wheat, maize, potato, banana, sugar and jaggery These can be divided into three groups.

1 **Monosaccharides** These are the simplest sugars consisting of three or more carbon atoms. Examples—Ribose, deoxyribose (pentoses), glucose, fructose and galactose (hexoses).

2 **Disaccharides** These are formed by the union of two monosaccharide units. Examples—Maltose = glucose + glucose, lactose = glucose + galactose, sucrose = glucose + fructose

3 **Polysaccharides** These comprise a large number (300 to over 1000) of monosaccharide units Examples—Starch, glycogen (animal starch), cellulose

Importance Most carbohydrates in the diet are glucose, fructose and galactose. Of these, fructose and galactose are readily converted to glucose in the liver Therefore, glucose is the only monosaccharide present in significant quantities in the blood

TABLE 1

Percentage of Carbohydrates in Some Common Foods and Their Calorific Values

Food	*Percentage of carbohydrate per 100 g of food*	*kcal per 100 g of food*
Sugar	99.4	398
Rice (raw, milled)	78 2	348
Wheat ('atta')	69 4	346
'Dal' (green gram)	69 4	361
Red gram	57.6	355
Banana	24 7	104
Potato	22 7	97
Mango (ripe)	11.8	50
Carrot	10.6	47
Cow's milk	4 4	47

The main end-product of carbohydrate digestion is glucose. One gram of which on complete combustion, yields 4.2 kilocalories (kcal). The calorific values of some carbohydrate containing food are given in Table 1.

One of the major results of carbohydrate intake is the maintenance of the blood glucose level at 100 mg per 100 ml. In the event of any extra glucose reaching the liver, it is converted into glycogen However, at the time of need, as in the case of early starvation, glycogen is again broken down into glucose [It is of interest to note that during prolonged starvation or fasting when the stores of glycogen have already been exhausted in the liver, glucose or glycogen may as well be synthesized by the degradation of tissue proteins or fats.]

FATS

These compounds consist of carbon, hydrogen and oxygen but chemically they are entirely different from carbohydrates in not having hydrogen and oxygen in the 2·1 ratio They are insoluble in water but soluble in solvents such as acetone, benzene, chloroform and ether Fats are made up of fatty acids and glycerol Groundnut, almond, coconut, butter and ghee are some of the rich sources of fats

Importance Energy production is one of the most important functions of fats One gram of it, on complete combustion, yields about 9 kcal (also see Table 2) Fat is stored in the body in the form of adipose tissue and can be utilized at the time of need It also protects many important organs in the body by forming shock-absorbing pads around them Fat is also an efficient insulator against cold. Since vitamins A, D, E and K are fat-soluble, they aid in their absorption in the body

PROTEINS

The term protein was coined in 1838, by a Dutch biochemist, Mulder, from the Greek word 'protios' which means 'of the first rank' Chemically, these are strikingly different from other foodstuffs as they always contain nitrogen and usually sulphur in addition to carbon, hydrogen and oxygen They are solely made up of amino acids. Their complete hydrolysis yields about twenty different amino acids In a protein these are united to one another by peptide bonds

TABLE 2

Percentage of Fats in Some Common Foods and Their Calorific Values

Food	*Percentage of fat per 100 g of food*	*kcal per 100 g of food*
Vegetable cooking oil	100 0	900
Vanaspati	100 0	900
Ghee (fresh)	99 5	895
Butter	81 0	729
Oil seeds and nuts	37 0 – 64 5	537 – 687
Mutton	13 3	194
Egg	13 3	173
Cow's milk	4 1	67

Since the peptide bonds are repeated between different amino acids, they constitute the backbone of the protein molecule Therefore, a protein is also described as a polypeptide chain.

The following points are very specific in respect of the structure of proteins: (a) each protein consists of a fixed number of amino acids, (b) the order in which the various amino acids are arranged is highly specific, and (c) the protein chain is wound in a spiral manner like a spring. Or, the chains may lie parallel to one another to form a pleated sheet-like structure

Egg, fish, meat, legumes, particularly soybean, are major sources of proteins (see Table 3)

TABLE 3
Protein Content of Some Common Foods

Food	*Protein content (g per 100 g of food)*
Soybean	43.2
Groundnut	26 7
Pulses ('dals' split and decorticated)	21 0-28.0
Legumes (whole)	17 0-25 0
Nuts, oilseeds and fresh coconut	16 0-32.0
Fish (fresh)	15 0-23 0
Egg	13 0
Dry coconut	6 8
Cereals	6.0-13 0
Milk	3.2- 4.3

Importance Proteins have been described as the 'stuff of life' as they form the basal framework of protoplasm Like carbohydrates and fats, proteins can also be broken down to release energy One gram of protein, on complete combustion, yields 5.6 **kcal** Also, during the degradation of amino acids, the heat produced by the body is increased, which is referred to as specific dynamic action

Proteins function as regulators in the form of certain enzymes and some hormones. While enzymes catalyze all the reactions which control the breakdown and synthetic processes in the body, hormones regulate the physiological processes

MINERALS

A wide variety of mineral salts (inorganic compounds) are necessary for life processes. They are usually required in small quantities to build bones and teeth They are also needed in blood coagulation, functioning of muscles, nerves, thyroid gland and formation of red blood corpuscles The sources and requirements of some minerals in the diet per day are given in Table 4

VITAMINS

Vitamins are organic substances present in small amounts in natural foodstuffs, and are essential for various cell functions. Unlike amino acids, vitamins do not enter into the tissue structure.

TABLE 4
Minerals—Sources and Requirements

Mineral	*Source*	*Requirement*
Chloride	Fish, meat, eggs, milk and as cooking and table salt	3500 mg
Sodium	Fish, meat, eggs, milk and as cooking and table salt	3500 mg
Calcium	Milk, cheese, eggs, green vegetables and some fish	1200 mg
Phosphorus	Cheese, oatmeal, liver and kidney	1200 mg
Potassium	All foods	1000 mg
Magnesium	All green vegetables and green leaves	400 mg
Iron	Liver, kidney, meat, egg-yolk, whole-meal bread and green vegetables	18 mg
Zinc	Milk, colostrum (mammal's first milk after parturition)	15 mg
Iodine	Salt water fish, cod-liver oil, dried kelp and vegetable grown in soil containing iodine	0.15 mg

They are divided into two main groups.

Fat-soluble vitamins A, D, E and K

Water-soluble vitamins B complex, C

Although these have no energy value, they are important accessory substances which contribute to the maintenance of health. Plants can make vitamins from simple substances, but animals are unable to synthesize them and obtain them directly or indirectly from plants. Their role in causing several deficiency disorders has been demonstrated only during the present century. Some vitamins and their sources are listed in Table 5.

TABLE 5
Major Sources of Vitamins

Vitamin	*Source*
Vitamin A	Milk, butter, cheese, egg-yolk, liver oils of fishes, green and yellow vegetables
Vitamin D	Egg yolk, whole milk, fish oils and fish liver
Vitamin E	Vegetable seed oils, egg, lettuce, sweet potato and meat
Vitamin K	Egg-yolk, cheese, liver, alfalfa, lettuce, cabbage, tomato, cauliflower, soybean
Vitamin B_1 Thiamine	Unpolished rice, wheat germ, lettuce, cabbage, soybean, meat
Vitamin B_2 Riboflavin	Milk, cheese, eggs, liver, kidney, heart, green leafy vegetables, wheat germ and germinated peas
Niacin	Lean meat, fish, eggs, milk, fruits, vegetables, outer coats (bran) of cereals
Vitamin B_6 Pyridoxine	Yeast, liver, egg-yolk, meat, rice polishings and bran of wheat and maize
Folic acid	Dark green leafy vegetables, liver, kidney and yeast
Vitamin B_{12} Cyanocobalamin	Milk, cheese, liver, kidney, lean meat
Vitamin C Ascorbic acid	Citrus fruits, mango, guava, grapes, amla, green and red peppers

WATER

Human body contains about 60 per cent water. Body water comes from three main sources—food, drinks and body metabolism. An adult ordinarily obtains nearly 700-1000 ml water daily from solid or semisolid food. About 600-1200 ml water is consumed through liquids taken everyday. The human body produces approximately 300-400 ml water per day as a result of oxidation of carbohydrates, fats and proteins.

Water is essential for the proper functioning of the body because (i) it provides moist environment required by cells in the body, (ii) it helps to moisten food, (iii) it assists in the regulation of body temperature as a constituent of perspiration, (iv) it transports various useful substances to the cells, being the major component of blood and tissue fluid and excretes certain metabolic wastes outside the body; (v) it dilutes waste products and poisonous substances; and (vi) it contributes to the formation of urine and faeces.

Some Useful Terms

Acetone The simplest type of saturated ketone; useful solvent, a basic material for organic synthesis

Amino Acid A group of organic acids having the amino group (NH_3) attached to the carbon next to the carboxyl group (COOH); some 24 amino acids commonly occur in proteins

Benzene A colourless, highly inflammable liquid, soluble in alcohol, acetone, etc , imiscible in water, a solvent for fats, resins, the simplest member of aromatic hydrocarbons (C_6H_6)

Calorie A thermal unit, the amount of heat required to raise the temperature of 1g of water by 1°C (from 14.5°C – 15 5°C), equal to 4.184 joule of the S I system

Carbohydrate An organic compound of carbon, hydrogen and oxygen in which the atoms of hydrogen and oxygen are in the ratio 2.1

Chloroform Trichloromethane ($CHCl_3$), a colourless liquid of peculiar odour, solvent for fats, oils, resins and rubber, also used as an anaesthetic

Disaccharide Carbohydrates derived from two molecules of monosaccharides by elimination of a molecule of water, e.g., maltose, sucrose

Fatty Acids Monobasic aliphatic carboxylic acids, a constituent of fat, insoluble in water

Fructose Fruit sugar or laevulose ($C_6H_{12}O_6$)

Galactose A dextro-rotatory hexose sugar of the formula $CH_2OH\ (CHOH)_4\ CHO$

Glycerol A three-carbon alcohol which is a constituent of all fats

Glucose A common six-carbon sugar, chief fuel in the living system

Hexoses A group of monosaccharides containing six oxygen atoms, six carbon sugar

Kilocalorie One thousand calories (kcal)

Maltose A white crystalline disaccharide ($C_{12}H_{22}O_{11}$)

Monosaccharide The simplest carbohydrates, also known as simple sugars

Pentoses A group of monosaccharides containing five oxygen atoms, five carbon sugar

Peptide Bond Link between amino acids in proteins, formed when the amino group joins with the carboxyl group of the adjacent amino acid with elimination of a water molecule

Polypeptide A chain of amino acids forming the primary structure of protein

Polysaccharide Complex carbohydrates consisting of many hexose units such as starch, glycogen and cellulose

Ribose A pentose sugar, constituent of ribonucleic acid

Vitamin A group of unrelated organic substances in food, essential in small amounts for normal metabolism, vitamins often serve as coenzymes

Things to Do

A CARBOHYDRATES

1 Dissolve 500 mg of each of the following carbohydrates in 50 ml of water, and notice their solubility (i) glucose (ii) fructose (iii) lactose (iv) maltose (v) sucrose (vi) starch Bring the solution to a boil if any of them remains undissolved in cold water

2 Add one drop of Molisch reagent (5 g of α-naphthol in 100 ml of 95% ethanol) to 2 5 ml of the carbohydrate solution Carefully pour 2 ml of concentrated sulphuric acid along the inner side of the test tube. Comment on the change that occurs at the junction where the two liquids meet

3 To 2 5 ml of Benedict's reagent, add 4 drops of the sugar solution Boil the mixture for 2-3 minutes in a water bath What is the colour of the precipitate that is formed? Is any change observed in case of sucrose?

4 Add two drops of concentrated sulphuric acid to 3 ml of sucrose solution and boil for 2 or 3 minutes Neutralize with 3 or 4 drops of 20% sodium hydroxide solution Now carry out Benedict's test as above Explain the result

5 Add two drops of dilute iodine (5 ml of Lugol's iodine and 95 ml of water) to 2 ml of starch solution (mashed potatoes or boiled rice in hot water may be used) Report your observations

B. FATS

6 Rub some fat onto a piece of ordinary writing paper What change is observed on the paper?

7 Take two drops of mustard oil in a test tube and add one ml of water. Record your observations on the solubility

8 Take two drops of olive or mustard oil in each of five, different, labelled test tubes To tube 1, add one ml of acetone, to tube 2, one ml of benzene, to tube 3, one ml of ether, to tube 4, one ml of chloroform; and to tube 5, one ml of carbon tetrachloride Shake the tubes and report the solubility in each case.

C. PROTEINS

Prepare protein extract or solution· (a) by diluting egg albumen (1·3) with water (b) by grinding either soybean seeds or soaked pulses into a fine paste and diluting with water (filter through a thin layer of cotton or cheese cloth), and (c) by grinding 10-15 g of liver or muscle of rat or frog into a fine paste and diluting with 40-50 ml of water.

9 To one ml of the protein solution, add drop by drop any strong mineral acid (hydrochloric, nitric or sulphuric) Report the change, if any

10 To one ml of the protein solution, add drop by drop either 5% mercuric chloride, or copper sulphate or lead acetate solution. Observe and report the change in the protein solution

11 Add one ml of 10% potassium hydroxide or sodium hydroxide to 2 or 3 ml of the protein solution and shake Mix two drops of 3% copper sulphate If no decisive colour develops, add another drop or two of copper sulphate. What is the change in colour?

12 Add one ml of 20% sodium hydroxide to 3 ml of egg albumen (white of egg) in a test tube Heat gently until it boils. The albumen coagulates and becomes opaque Remove the test tube from the source of heat and smell Can you detect the substance? What do you conclude from this experiment?

D. MINERALS, VITAMINS AND WATER

13 Select two sets of chickens of equal weight, age and breed. Feed, for a month or more, one set only on polished rice and the other on rice from which the outer husk has not been removed. Notice the differences in the health of the chickens of both groups and interpret your observations.

14 Prepare two alternative diet charts—one for vegetarians and the other for nonvegetarians—suffering from iodine, calcium or vitamin A deficiencies

15 Make two groups of boys and girls in your class Ask one group to drink 12-15 glasses of water per day, and the other group be advised to reduce their intake of water to only 4-6 glasses per day. Each student of the group be requested: (a) to measure the quantity of the urine daily, and (b) to observe the colour of the urine How do you account for the differences you come across in each individual of the group?

Test Yourself

1 Fill in the blanks:
(a) Carbohydrates have hydrogen and oxygen in the ratio of ____.
(b) Fat is composed of ____ and ____
(c) Fat is stored in the body as ____ tissue.
(d) Proteins contain the elements ____, ____, ____, ____ and ____
(e) Of the foodstuffs, ____ produces the least energy on combustion.

2 Write critical notes on:
(a) carbohydrates (b) vitamins (c) water (d) minerals

3 Tick (✓) the correct answer:
(a) Which of the following sugars is present in considerable amount in the blood?
(i) galactose
(ii) glucose
(iii) sucrose
(iv) fructose

(b) Which of the following is water-soluble?
 (i) vitamin A
 (ii) vitamin K
 (iii) vitamin D
 (iv) vitamin C

4 Name the minerals required by the human body. Mention any four of their functions

5 What are the roles of the following in the human body?
(a) proteins (b) water (c) sugars (d) iron (e) vitamin B complex

Try to Answer

1 Do we eat food merely to satisfy the sense of taste? Argue

2 Why is lactic acid ($C_3H_6O_3$) not a carbohydrate although it satisfies the general formula of a carbohydrate?

3 Deoxyribose ($C_5H_{10}O_4$) does not conform to the general formula of a carbohydrate and yet it is a sugar. Explain.

4 Why is sucrose a non-reducing sugar?

5 In the event of prolonged fasting/starvation, what is the source of glucose?

6 What is the normal blood glucose level in man?

7 What happens to the extra glucose in the body when the carbohydrate intake is very high?

8 Which foodstuff yields the maximum amount of energy upon complete combustion?

9 When a person is suffering from diarrhoea, he is advised to avoid fats, why?

10 Is it true that
 (a) olive oil is completely soluble in ethanol?
 (b) sucrose, like maltose, is a reducing sugar because it reduces Benedict's reagent upon boiling?
 (c) in the event of prolonged fasting, glucose can be synthesized in the body from certain amino acids for maintaining the blood glucose level?
 (d) olive oil is more readily soluble in chloroform than in acetone?
 (e) the main difference between glucose and fructose is that glucose possesses a ketone group?
 (f) all mineral acids precipitate protein solutions?

11 When you fry your food in oil, which vitamins are generally lost?

12 Phosphorus is considered to be a vital mineral. Why?

13 Under what situations is a person usually advised to increase his intake of water?

12

Enzymes

Catalyst, Biocatalyst, Substrate, Inactivation, Optimal temperature, Optimal pH, Specificity, Activation, Inhibition, Reversibility

THE CHEMICAL COMPOSITION of foodstuffs indicates that they are complex molecules, and are too large to be absorbed by the cells lining the villi of the small intestine Also, they cannot be oxidized by the cells of the body for the release of energy unless they are broken down into simpler units. The splitting of various complex food molecules into their basic constituents, and their oxidation takes place with the aid of certain active substances, the enzymes. Almost all reactions in the living organisms take place under the influence of enzymes. These are produced by living cells. However, the enzymes are independent of living cells in their operation.

A crude extract of germinating grains, or moulds, has the capability of digesting starch because of the presence of an enzyme called amylase (diastase) The common meat tenderizer, papain, is also an enzyme, obtained from the fruits of papaya Fresh pineapples contain another protease which can liquify the usually semisolid gelatin. A large number of enzymes are known to be involved in the successive steps of the processes of respiration and photosynthesis.

History

As far back as 1752, Réaumur performed an ingenious experiment showing that stomach juice had a distinct digestive power. The birds of prey eject from their stomach, articles of food that they cannot digest. Taking advantage of this fact, he fed perforated metal tubes filled with different types of food materials to a kite He examined the condition of food upon regurgitation of the tubes. His conclusion was that food materials underwent a definite transformation, and it was due to the solvent (digestive) power of the stomach juice

In 1835, Berzelius observed that a mixture of active ferments from potatoes could break down starch faster than even sulphuric acid With great insight he predicted that all substances in living organisms are also synthesized under the influence of catalysts, and for these the name enzyme was introduced by Kühne in 1878 The term enzyme is derived from a Greek word meaning 'in yeast' because of its first detection in yeast cells.

Definition and Nomenclature

You are aware that chemical reactions occur as a result of collision between the reactant molecules. The energy required to make this collision forceful enough to result in a chemical reaction is called activation energy. Enzymes are proteins which act as biocatalysts, and lower this activation

energy. They speed up the rate of reaction without themselves being used up

The substance upon which an enzyme acts is called a substrate Most enzymes are named after their substrate by adding the suffix 'ase'. For example, maltase acts on maltose and uricase on uric acid Certain enzymes are designated on the basis of their function rather than the substrate. For instance, a dehydrogenase catalyzes the removal of hydrogen, and oxidase brings about the addition of oxygen. For certain enzymes, their original names are still used, e g , pepsin, trypsin, ptyalin The suffix 'lytic' (from lysis meaning breakdown) is also used to indicate enzyme activity on classes of substances such as proteins (proteolytic), fats (lipolytic) and carbohydrates (sucrolytic).

Characteristics

1 All enzymes are proteins and share common properties They form colloidal solutions and are of high molecular weight

2 Enzymes are associated with every chemical reaction that occurs in the living system

3 Enzymes participate in both the catabolic and anabolic reactions For example, proteins are broken down into amino acids by enzymes; and the amino acids are also joined together by enzymes

4 Enzymes generally accelerate biochemical reactions by reducing the energy requirement (activation energy)

5 Enzymes do not alter the amount or nature of the product

6 Enzymes do not affect the amount of energy released or absorbed during the reaction

7 Enzymes retain their identity at the end of the reaction, as at the beginning In other words, they are not destroyed by the reactions they catalyze and so can be used again. However, a given molecule of an enzyme cannot be used indefinitely because it is readily inactivated by heat or action of acid, and so on Conversely, inorganic catalysts are highly stable and can be used over and over again.

8 Extremely small amounts of enzymes are able to bring about measurable changes

9 Enzymes catalyze biochemical reactions at significantly lower temperatures. For example, to hydrolyze 5 ml of 1% starch solution, it is essential to add five drops of concentrated sulphuric acid and then boil the mixture for over fifteen minutes. On the other hand, even 100 times diluted saliva containing salivary amylase would require just 8-10 minutes to hydrolyze the same quantity of starch at only 37° C.

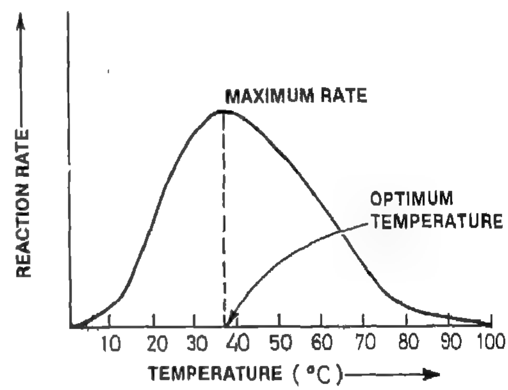


Fig 12-1 Effect of temperature on the reaction rate of enzyme

10 Most enzymes show their maximum activity at body temperature (37° C) called the optimal temperature (Fig. 12-1). With gradual increase to 50° C or so, there is a slight fall in the rate of reaction. At temperatures exceeding 57° C, the velocity begins to slow down significantly, so much so that the enzyme is completely destroyed at 100° C. It has undergone an irreversible change and thus its activity cannot be restored. However, at extremely low temperature (0°C – 2°C), the enzyme is completely inactivated, temporarily, but again with the progressive rise in temperature, its activity can be regained

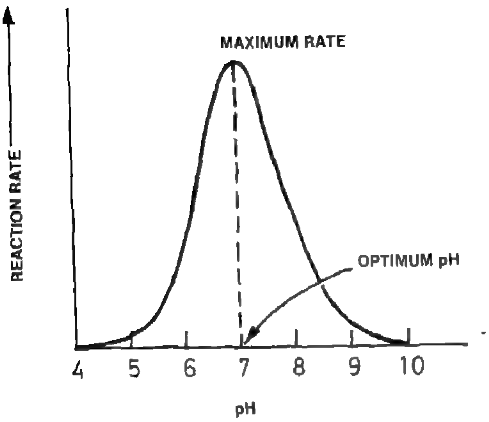


Fig 12-2 Effect of pH on the reaction rate of enzyme

11 Enzymes are sensitive to change in pH (hydrogen ion concentration) in the reaction medium (Fig 12-2) In fact, every enzyme works best at a specific pH called the optimal pH Most enzymes display maximum activity at or around neutral pH. Excessive acidity or alkalinity renders them inactive. However, a few digestive enzymes operate either in distinctly acidic or alkaline medium For instance, the stomach enzyme, pepsin, functions best at a pH of 2 0, whereas the pancreatic enzyme, trypsin, has an optimal pH of 8 0.

12 Enzymes are specific in their action, i e , they are capable of acting on a predetermined substrate. An enzyme that can hydrolyze starch is unable to hydrolyze cellulose. For this, another enzyme, cellulase, is needed The degree of specificity, however, varies. Most intracellular enzymes are specific, whereas certain digestive enzymes work on a comparatively wide range of related compounds

13 Many enzymes cannot act on their own and require the help of some substances for their activation and for speeding up the rate of reaction (Fig 12-3) Such substances are called activators This activation is due to the effect of certain ions such as Na^+, K^+, Ca^{++}, Mg^{++}, Mn^{++} You are now familiar with the stomach enzyme pepsin This is produced in the inactive form as pepsinogen by one type of cells in the gastric glands Pepsinogen is converted into the active form, pepsin, by HCl secreted by certain other cells of the gastric glands. Similarly, when pancreatic juice containing the inactive trypsinogen is poured into the duodenum, it comes in contact with another enzyme, enterokinase, secreted by the mucosal layer of the

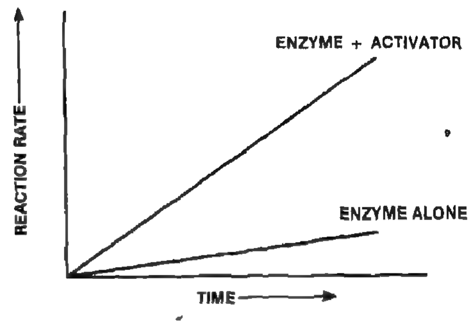


Fig 12-3 Effect of activator on the reaction rate of enzyme

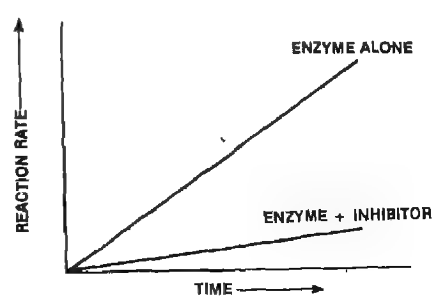


Fig 12-4 Effect of inhibitor on the reaction rate of enzyme

duodenum, which in turn, converts trypsinogen into the active form, trypsin

14 Certain substances called inhibitors slow down the rate of enzymatic reaction (Fig 12-4). For example, mercury and arsenic ions inhibit the activity of a wide range of enzymes Also, some antibiotics are effective inhibitors for bacterial growth since they hamper their protein synthesis

15 Most enzymes can work in either direction, i e., they are capable of operating reversibly In other words, one and the same enzyme can catalyze the breakdown as well as the synthesis of the substance. However, in many instances, the reversibility of reaction has not yet been demonstrated.

Some Useful Terms

Activator A chemical substance which helps enzymes to become functional

Amylase An enzyme that catalyzes the hydrolysis of starch and glycogen and converts them into smaller units such as sugar

Antibiotic A chemical substance produced by a living organism (mainly by microorganisms) which inhibit the growth of other microorganisms, some can also be produced synthetically

Biocatalyst A catalyst of organic origin, an enzyme which accelerates biochemical reactions

Colloidal Solution A stable, uniform mixture, usually liquid, in which some of the constituents are larger than molecular size

Dehydrogenase An enzyme that catalyzes oxidation by removal of hydrogen

Duodenum The first part of the small intestine of the vertebrates, situated posteriorly to the stomach

Enterokinase A substance which activates the trypsinogen produced by the pancreas into trypsin

Gelatin A colourless, odourless, tasteless, jelly-like protein generally obtained from horn, bones, and hide

Hydrolysis A chemical reaction in which a complex compound is split into simpler ones by chemical addition of water

Inhibitors A substance that limits or suppresses the catalytic activity

Maltase An enzyme that catalyzes the hydrolysis of maltose and other α- glucosides

Oxidase An enzyme that promotes oxidation by addition of oxygen

Papain A protein-digesting enzyme, present in the unripe fruit and green leaf of papaya, used as a meat tenderizer

Pepsin A stomach enzyme that catalyzes protein digestion in acidic medium

Pepsinogen An inactive precursor of pepsin

pH A symbol used to indicate acidity or alkalinity; a logarithmic index for the hydrogen ion concentration in aqueous solution

Ptyalin An enzyme found in saliva that catalyzes the breakdown of starch into sugar

Trypsin A pancreatic protein-digesting enzyme active in the intestine

Trypsinogen An inactive precursor of trypsin

Uric Acid An acid of the purine group, usually an excretory product

Uricase An enzyme that catalyzes the oxidation of uric acid, usually occurring in liver and kidney

Villi (sing villus) Small finger-like projections from the surface of a membrane (such as of the small intestine)

Things to Do

1 Take equal quantities of either minced meat or white of a boiled egg in two test tubes and label them as A and B. Extract juice (or prepare pulp) from the leaves (or unripe fruits) of papaya Add one half of the juice (or pulp) to tube A and mix. Boil the other half of the juice (or pulp) for 30 seconds, cool, add it to tube B and mix the contents Note the effect after a few hours Compare the results.

2 Prepare a solution of saliva by keeping 20 ml of water in your (cleaned) mouth for a minute. Transfer it to a beaker and filter Also prepare 1% solution of starch separately Shake thoroughly equal quantities of starch and saliva solutions in a test tube maintained at body temperature In another tube, mix the starch solution with distilled water instead of saliva. Compare the changes in the colour after adding a drop of iodine solution to a drop each of both the mixtures on a piece of tile, after every 30 seconds

Test Yourself

1 Match the words in Column I with the phrases in Column II

Column I	*Column II*
(a) dehydrogenase	(i) joins amino acids
(b) substrate	(ii) adds oxygen
(c) oxidase	(iii) acts on starch
(d) peptide bond	(iv) acts on protein
(e) pepsin	(v) removes hydrogen
	(vi) on which enzymes act

2 Give five characteristics of enzymes

3 Fill in the blanks·
   - (a) The inactive form of the enzyme trypsin is called__________.
   - (b) Pepsin functions best at a pH of__________.
   - (c) Metals which are required by proteins to act as enzymes are known as________
   - (d) Most enzymes have names ending with__________
   - (e) Starch is digested by an enzyme called________

4 Explain in a single sentence what is meant by,
   - (a) reversible reaction
   - (b) substrate
   - (c) inhibitor
   - (d) optimal pH
   - (e) enzyme

5 Mark true (T) or false (F)
   - (a) All proteins are enzymes
   - (b) Enzymes are required in same amount as substrates.
   - (c) Enzymes work best at optimal pH
   - (d) Enzymes are irreversibly inactivated at low temperatures
   - (e) Pepsinogen is the inactive form of pepsin

Try to Answer

1 Mention the three main properties of enzymes that differentiate them from inorganic catalysts

2 What will happen if
   - (a) a hawk is experimentally fed with perforated capsules filled with pork, mutton or cheese ?
   - (b) dilute molasses is inoculated with yeast cells ?
   - (c) starch is made to react with dilute saliva at 37° C ?
   - (d) starch is made to react with dilute saliva at 2° C ?
   - (e) starch is made to react with dilute saliva at 100° C ?

(f) chewed rice and potatoes make entry into the stomach ?

(g) saliva is first boiled at 100° C for 30 seconds and then allowed to react with starch at 37° C ?

3 The activity of an enzyme is directly proportional to the rise in temperature Is it true or false ?

4 Is it correct that

(a) some breakdown and synthesis reactions take place in the body without the aid of enzymes ?

(b) an enzyme once exposed to 100° C for half a minute completely regains its activity at 37°C?

(c) an enzyme cooled to O° C for six hours is able to regain its activity at 37° C ?

5 How are termites capable of digesting cellulose, whereas most species of plants and animals cannot ?

6 In what ways are the respiratory enzymes different from digestive enzymes ?

7 In the stomach and the small intestine, the enzymes for digestion of proteins are secreted in an inactive form Why ?

8 Why do not an animal's digestive enzymes digest its own tissues of the digestive tract?

9 Discuss the economic importance of enzymes secreted by bacteria

10 Why are antibiotics very effective in the treatment of certain bacterial infections?

11 How is phenylketonuria (PKU) caused?

12 How do enzymes serve to control and maintain life? Is life impossible without them?

13

Plant Nutrition

History, Chemical energy, Photosynthetic machinery, Light reaction, Dark reaction, Factors, Carbon cycle, Macronutrients, Micronutrients, Mineral deficiency, Autotrophs, Heterotrophs, Saprophytes, Parasites, Symbionts

GREEN PLANTS, like other organisms, also need nutrition for their survival The nutrients are inorganic salts (mineral elements), water and organic substances. They constitute the main components of the plant body and are required for the biosynthesis of cells, tissues, metabolic components, and enzymes which regulate metabolism. Of these substances, the mineral elements are contributed by decaying rocks which ultimately form the soil. The minerals are absorbed through roots and transported to the rest of the plant body.

The organic nutrients are manufactured by the green plants themselves with the help of atmospheric carbon dioxide, water and solar energy (photosynthesis), a feat not accomplishable by the animals. This ability is unique to green plants, and they are, therefore, classified as autotrophs. Photosynthesis also replenishes oxygen of our atmosphere which is needed for many metabolic activities. The maintenance of 21 per cent oxygen content of our environment is entirely due to this process. Through photosynthesis, plants are able to synthesize all the organic molecules associated with life on earth. All other organisms derive nutrients from plants directly or indirectly for their normal growth and development as they consume either green plants or creatures surviving on green plants. Photosynthesis is thus, an essential rung in the maintenance of the biological food chain.

In this chapter we will see as to how plants manufacture and obtain these substances, which are the essential elements needed by them for this purpose, and what is their impact on plants, also, how is the biological food chain properly maintained

Photosynthesis

You have already learnt that for all the activities of your life, you spend energy stored in your body—even when you play, eat, or sleep. You also know that this energy comes to you from the food you consume. But, how is this energy produced and stored in your foodstuffs? Except for nuclear energy, used for generating electricity, all the energy so vital for our survival is derived from the sun. The solar energy becomes available to us as chemical energy through the agency of green plants. They alone are capable of harnessing the sun's rays, and converting the atmospheric carbon dioxide and water into sugar and other organic molecules through photosynthesis or carbon assimilation (Fig. 13-1) If we were to compare the output of the world's steel

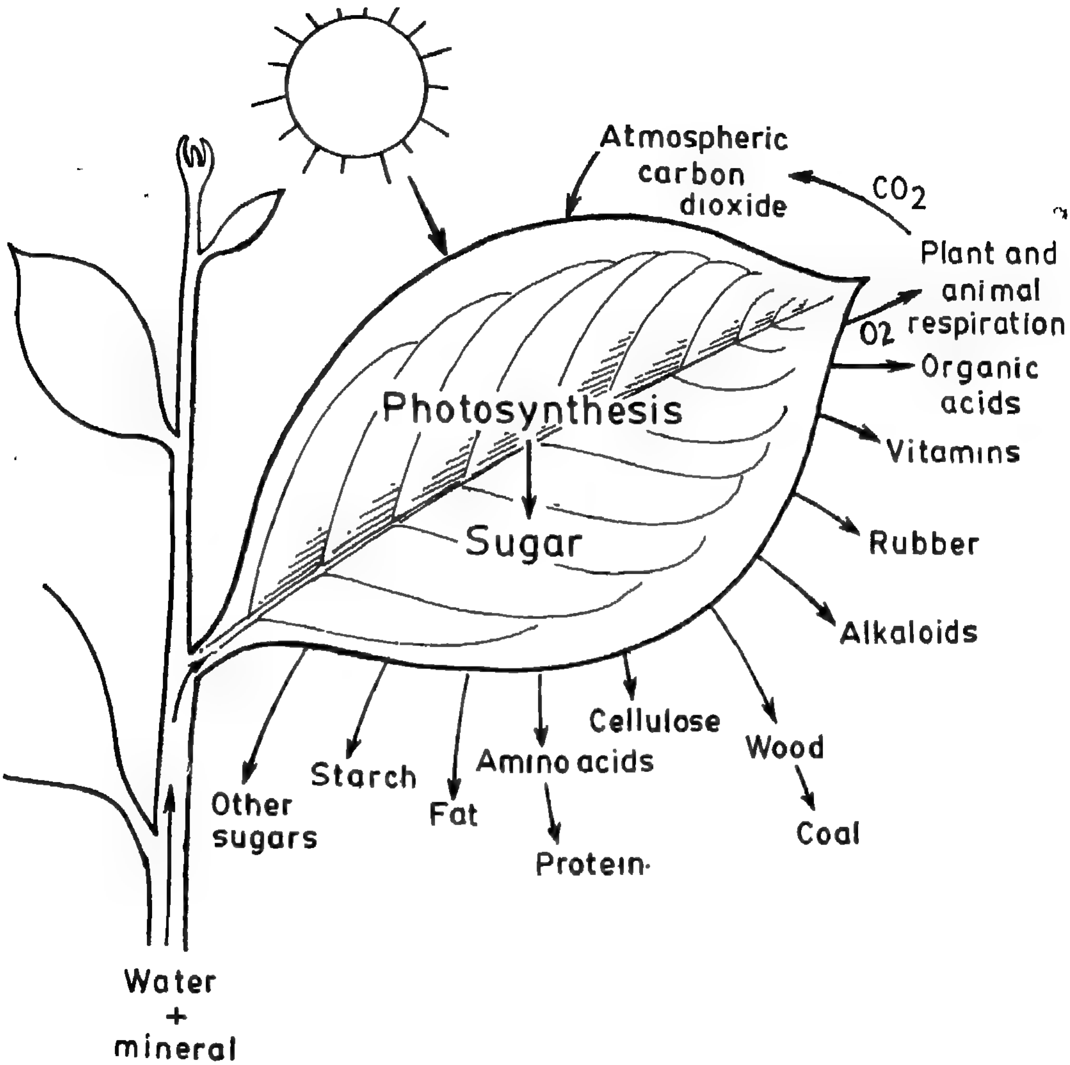


Fig. 13·1 Role of solar energy in photosynthesis. by absorbing sunlight, and water and minerals from soil, green leaves are capable of synthesizing several products

plants or cement factories with the synthesis of food material by plants, the latter would excel them in production as well as in efficiency, that too without polluting our environment.

Through photosynthesis a constant source of organic fuel is assured as long as the green cells are capable of capturing light energy to make sugars and starch.

Let us try to understand as to how this complicated task, so crucial for our existence, is accomplished by the green plants.

As early as 1772, an English scientist, Priestley observed for the first time that green plants had the ability to purify air in the presence of light A

couple of years later, this purifying principle was identified by a Dutch physician, Jan Ingen-Housz, to be oxygen. According to him, light was absorbed by the green plants which transformed CO_2 and H_2O into carbohydrates, releasing O_2. He formulated the following equation for photosynthesis:

$$CO_2 + H_2O \xrightarrow[\text{green plants}]{\text{light}} O_2 + \text{carbohydrates}$$

Subsequently it was found that there was a quantitative relationship between the intake of CO_2 and release of O_2 as given below.

$$6\,CO_2 + 12\,H_2O \xrightarrow[\text{chlorophyll}]{\text{light}} \text{sugar} + 6\,O_2 + 6\,H_2O$$

Van Niel postulated that O_2 was released by H_2O and not CO_2 Later it was confirmed by him experimentally Thus, considering the above equations, it is understandable that solar energy is initially absorbed by chlorophyll, the green pigment present in the chloroplasts of plant cells. It then triggers a number of reactions involved in photosynthesis.

The energy from the sun or from artificial light sources that travels to us is in the form of packets called photons The energy of a photon is called a quantum ($h\nu$) The absorbed quanta can be lost as fluorescence and/or heat (Fig. 13-2). Under suitable conditions, the absorbed light triggers a photochemical reaction that induces splitting of water, causes release of oxygen (from water), and helps in the synthesis of a reducing agent which then converts carbon dioxide to carbohydrate

Carbohydrates, proteins and fats, the major components of food, are the stored forms of chemical energy These are utilized by the cell during various metabolic processes The chemical or potential energy of foodstuffs is locked in the covalent bonds between the atoms of a molecule. For example, 180 g of glucose carry a potential energy of about 6,86,000 calories between the atoms of C, H and O. The energy released from

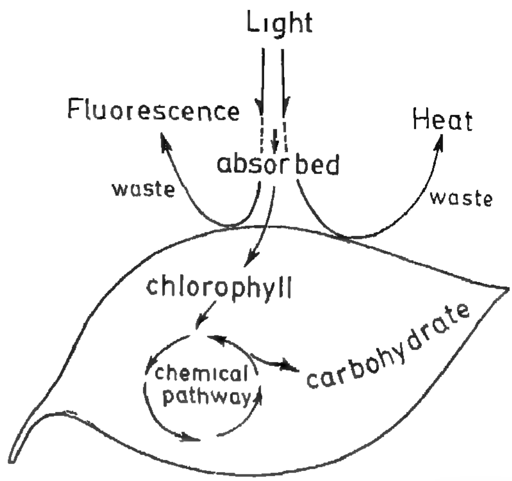


Fig 13-2 Fate of sunlight as it strikes leaves part of it is lost as heat and in fluorescence and the rest is utilized in photosynthesis

foodstuffs is transformed and transported as adenosine triphosphate (ATP), a compound found in all cells It has two terminal high energy bonds containing about 7,300 calories. The high energy ~ P-bonds enable the cell to accumulate a large quantity of energy and keep it ready for use The reaction $ATP \rightleftharpoons ADP + P_i$ (inorganic phosphate) releases the energy contained in the ~ P-bond. ADP (adenosine diphosphate) and ATP play a central role between chemical processes that liberate energy and those which store or transform it

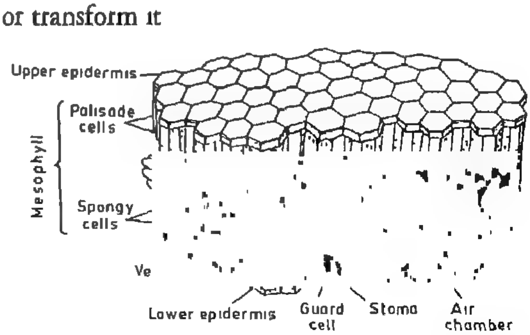
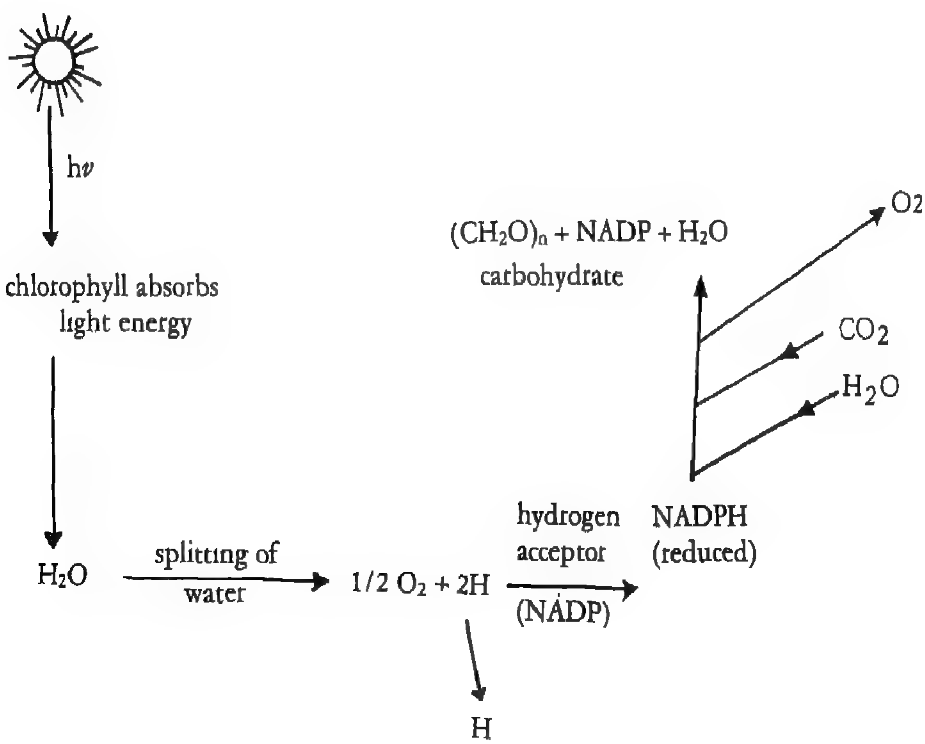


Fig. 13-3 Internal organization of leaf· chloroplast-containing cells (mesophyll) absorb sunlight, stomata help in exchange of gases, and vascular tissues (vein) transport nutrients

The CO_2 entering into the reaction comes to the green cells of leaves and/or stem from the air by way of stomata. It then diffuses to the other parts of the leaf through intercellular spaces. Leaf, the main photosynthetic organ, is made up of several layers of mesophyll cells supplied with veins or conducting strands The veins are so disposed that every mesophyll cell remains in close contact with them (Fig. 13-3) They maintain a two-way transport system—carrying the raw materials to the leaf, and removing photosynthetic products and other substances away from the leaf

The photosynthetic machinery of higher plants is contained in chloroplasts. A single cell may have as many as 300 or more of these green plastids The chloroplast consists of grana which are distributed in stroma (for details, see Chapter 3). Grana contain light-absorbing pigments (chlorophylls and carotenoids) and proteins which facilitate the oxidation of water and reduction of carbon dioxide The stroma contains many enzymatic proteins involved in the metabolic transformations of sugars and starches as well as for other biochemical activities.

The entire reaction, right from the absorption of light by the chlorophyll molecule until the formation of the reducing agent and energy-rich compounds can be summarized as follows:



THE PROCESS

Photosynthesis can be separated into two sets of reactions—one strictly dependent upon light called photophosphorylation or light reaction, and the other independent of light or dark reaction (Fig. 13-4)

The Light Reaction It is also called the Hill reaction R Hill, an English biochemist, was the first to observe that chloroplasts when isolated from cells, and illuminated in the presence of artificial acceptors, caused the release of oxygen and reduction of acceptors. Water served as the only hydrogen donor and carbon dioxide was not required. This means that light reaction results in the evolution of O_2. Nicotinamide adenine dinucleotide phosphate (NADP), a naturally occurring compound acting in energy transfer reactions, has been shown to serve as hydrogen acceptor in the grana It is reduced to NADPH in the process ATP is also formed from ADP and Pi during light dependent reaction. These products of light reaction are then utilized in dark reaction for the reduction of carbon dioxide

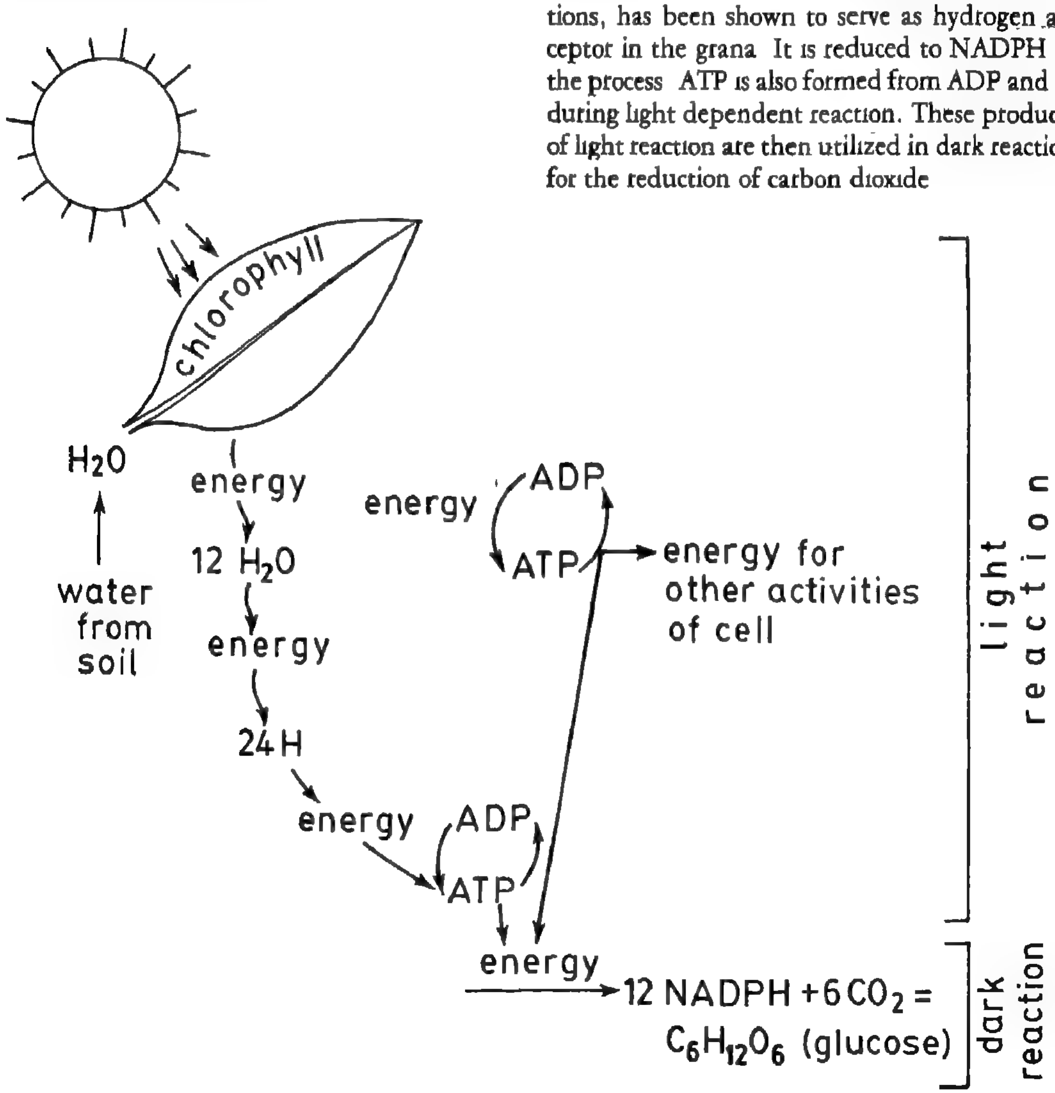


Fig. 13-4 Light and dark reactions in photosynthesis

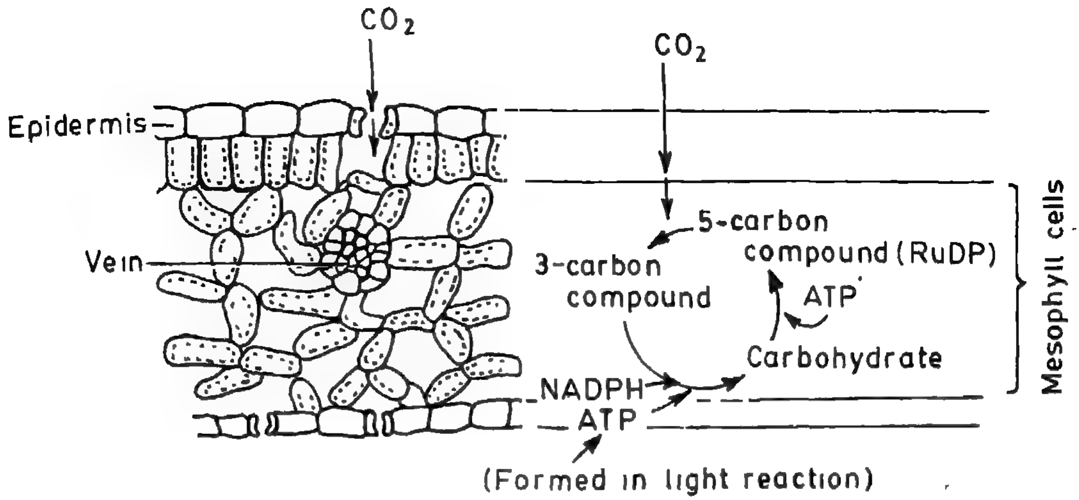


Fig 13-5 C_3 cycle of photosynthesis first product is a 3-carbon compound

The production of ATP during light reaction is called photophosphorylation. Green plants are thus able to produce ATP without utilizing stored food. The plants, therefore, produce excess of carbohydrates which can be used by other organisms

The Dark Reaction The biosynthesis of carbohydrates from CO_2 takes place by using ATP and NADPH formed during the light reaction. There are two major pathways by which CO_2 fixation occurs One leads to the formation of an initial 3-carbon product (C_3 system), and in the other a 4-carbon product (C_4 system) is formed.

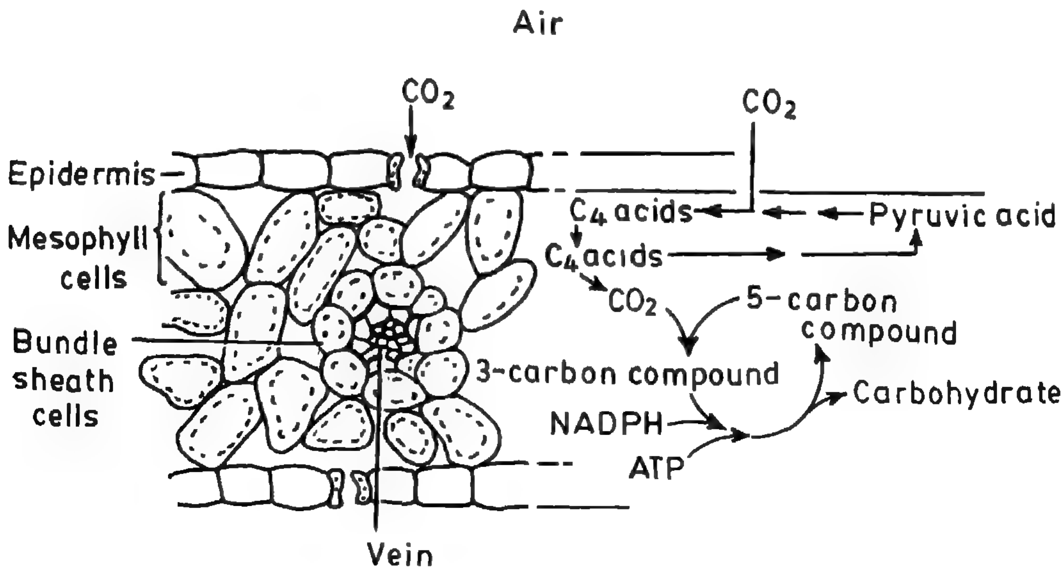


Fig 13-6 C_4 cycle of photosynthesis initial product is a 4-carbon compound

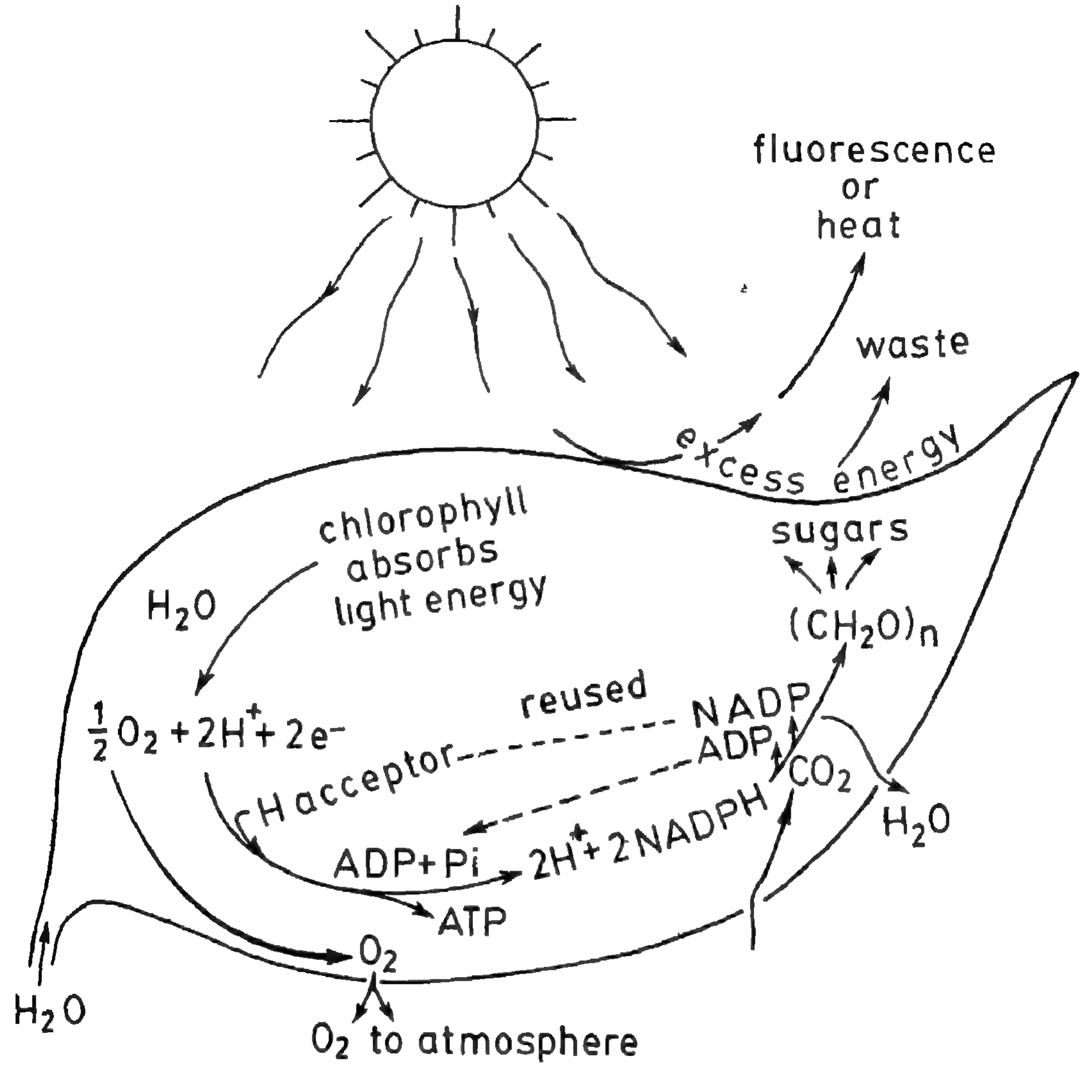


Fig 13-7 Summary of process of photosynthesis depicting absorption of solar energy, splitting of water, recycling of ATP and ultimate synthesis of carbohydrate

C_3 Cycle In this cycle, initially the atmospheric CO_2 combines with a 5-carbon sugar, which forms a transient 6-carbon compound (C_6) The C_6 compound breaks down to form two molecules of 3-carbon compounds It is finally reduced through further reactions to form hexose sugars and other complex carbohydrates (Fig 13-5)

C_4 Cycle The C_3 cycle of CO_2 fixation is not the only means available to plants In some, the first stable intermediary is not a 3-carbon compound, but a 4-carbon compound In C_4 cycle the CO_2 fixation begins when this 4-carbon product breaks down to release CO_2 which is then picked

up by an enzyme to follow C_3 cycle to finally synthesize carbohydrates (Fig 13-6) The entire process of conversion of solar energy to chemical energy is summarized in Fig 13-7.

Plants using 4-carbon cycle have very fundamental differences to 3-carbon pathway plants in their leaf structure The C_4 plants, such as maize, sugarcane, and some grasses, have most of their chloroplasts in a special layer of cells which surrounds the leaf vein Carbon dioxide enters the mesophyll cells and undergoes a reaction to form a C_4 compound It is then further processed in these special cells to yield CO_2 This CO_2 then enters the C_3 reduction cycle. The C_4 plants have been found to be more efficient because they are able to thrive at low concentration of CO_2, they can grow fast at high temperatures and light intensities and in comparatively dry areas In C_3 plants, e g , temperate species, as much as 30 per cent of the CO_2 initially fixed into carbohydrates ends up being released as CO_2 In C_4 plants, however, the CO_2 released is trapped and incorporated back into the cycle Thus, all the CO_2 fixed can be stored as starch or used for plant growth

The C_4 system can be very useful in plant improvement programmes It can help towards increasing food supplies in hot, dry climates Selection of high-yielding strains of C_4 crops would produce larger harvests even under hostile climatic conditions Three high-yielding C_4 crop plants such as corn, sorghum and sugarcane are already being used Such plants will be quite useful for cultivation in scrubby or semi-desert areas of our country. It is also hoped that cross-breeding between a favourable C_3 crop plant and C_4 plant could result into incorporation of suitable factors from C_4 to C_3 plants enabling them to grow in unfavourable climates (like C_4 plants)

FACTORS AFFECTING PHOTOSYNTHESIS

Photosynthesis, as we have seen, is controlled by different external and internal factors The external or the environmental factors include light, CO_2, temperature and H_2O The internal factors are chlorophyll content, anatomy of the leaf, water content of protoplasm, and availability of photosynthetic enzymes

The rate of photosynthesis is proportional to the total amount of light received by the plant The excess amount of light, not really needed, is dissipated as heat The high concentration of CO_2 also affects the rate of photosynthesis favourably However, excess amount becomes toxic and lowers the rate. With an increase in temperature, the rate of photosynthesis also increases, but to a limited extent. The temperature acts as a limiting factor beyond a certain degree, because it affects other cellular processes and activity of enzymes Since water sets free the reducing hydrogen atom, and its quantity required is very small, it is seldom a limiting factor However, scarcity of water affects the closing of stomata and reduces the rate of diffusion of CO_2, thereby influencing the rate of photosynthesis

Photosynthetic rate has not been found to be proportional to the chlorophyll content. Thickness of leaf cuticle, the palisade cells, size and distribution of stomata, all these affect the process by influencing diffusion of CO_2. Photosynthesis does not take place in leaves illuminated in green light because green and yellow rays are reflected by leaves

PHOTOSYNTHESIS AND ENERGY FLOW IN BIOSPHERE (THE CARBON CYCLE)

The story of life on earth, as that of earth itself, revolves around the sun. Except for the recent utilization of atomic energy, the sun is the sole source of energy for almost all living forms The living cells obtain their energy from oxidized fuels called foods The basic food molecule is derived directly from solar energy through the process of photosynthesis

The compounds produced by the primary producer (green plants) then become the source of

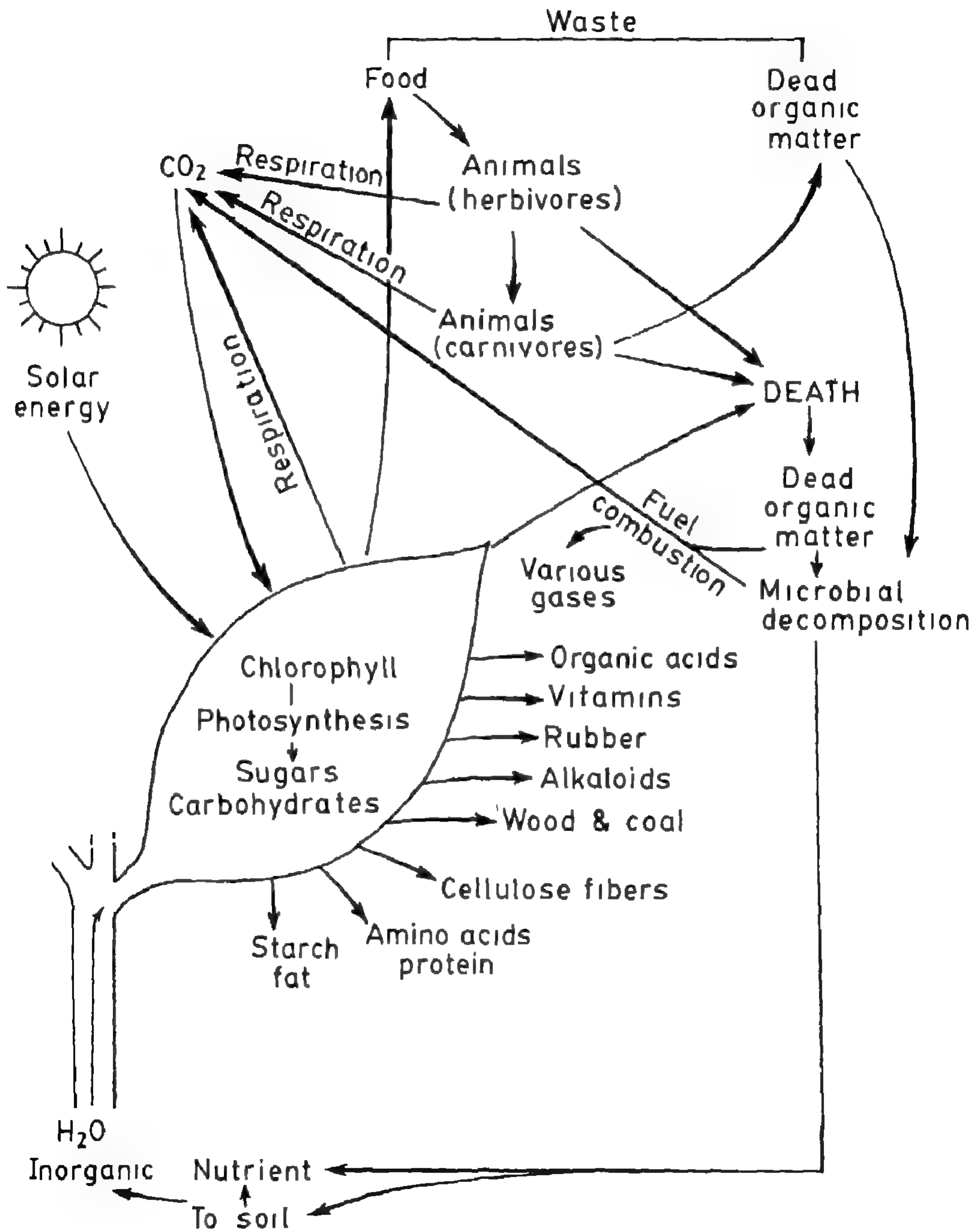


Fig 13-8 Green plants as natural factories which do not create any pollution

energy for the consumers at different levels Since man consumes either green plants or creatures thriving on green plants, he too, like other members (animals) of the biosphere, indirectly draws on solar energy The biologically important compounds, while travelling through this food chain, retain their organic state, and only a part of it is lost . To maintain this very important cycle in the biosphere, these compounds must return to the environment so that they can be picked up by the plants once again This step of decomposition of dead remains of plants and animals, and waste products of animals is carried out by bacteria and certain fungi

Other sources of energy such as peat and coal, natural oils, and gases are also derived from solar energy This is fossilized solar energy captured during photosynthesis by plants that died millions of years ago and have undergone various physical and chemical changes. Thus, the green plants and their capability to photosynthesize is man's major link with the energy of the sun (see Figs 13-8, 13-9).

Mineral Requirement of Plants

Plants require a wide variety of mineral elements for their structural organization For example, calcium is needed for cell wall synthesis, and in the formation of specific enzymes which regulate the metabolic processes. The minerals are absorbed from the soil through the root system and transported to the upper parts of the plant.

The specific mineral requirements of plants can be worked out by growing the seedling in a nutrient solution containing chemical salts. If grown in mineral solution lacking adequate quantities of some essential element, the plants will be unhealthy and will develop typical deficiency symptoms. These can then be attributed to the absence of that element. With such experimental techniques, it was possible to work out the essential mineral requirements of plants These mineral requirements are categorized into two groups (i) macronutrients (which are needed in large quantities), and (ii) micronutrients (which are needed in minute quantities).

MACRONUTRIENTS

These elements (carbon, hydrogen, oxygen, nitrogen and phosphorus) are the main building blocks of the plant body They are the components of protoplasm and constitute organic compounds of the plants. The cell walls are composed of C, H, and O, so also the fats and carbohydrates Proteins are made up mainly of C, H, O and N; and nucleic acids have P in addition. Sulphur is a constituent of a few amino acids which ultimately form proteins Without these amino acids, many important proteins cannot be synthesized, thus affecting metabolic processes Nitrogen is also an essential constituent of different proteins, nucleic acids and many other organic molecules. It is available in the form of nitrate or ammonia salts Deficiency of these substances causes pale leaves (chlorosis), rapid leaf fall, stunted growth and inhibition of cell division and respiration Besides these, the following elements are also essential for plant growth:

Calcium It is incorporated in the middle lamella of the cell wall thereby making the wall stiff and rigid Calcium promotes the development of root hairs, and activity of chloroplasts. Crystals of calcium oxalate and calcium sulphate occur in certain plants. Deficiency of calcium causes chlorotic patches on leaf and affects the root and shoot tip and enzymatic activities of the cell.

Magnesium Being a component of chlorophyll, it is essential for photosynthesis and for the activities of several enzymes In its deficiency, the leaves suffer from severe and typical chlorosis.

Phosphorus It is present mainly as a structural component of nucleic acids (DNA and RNA), and part of certain fatty substances Phosphorus is necessary for the functioning of mitochondria. Its deficiency prevents the formation of new DNA and RNA and energy transfer steps in the cell.

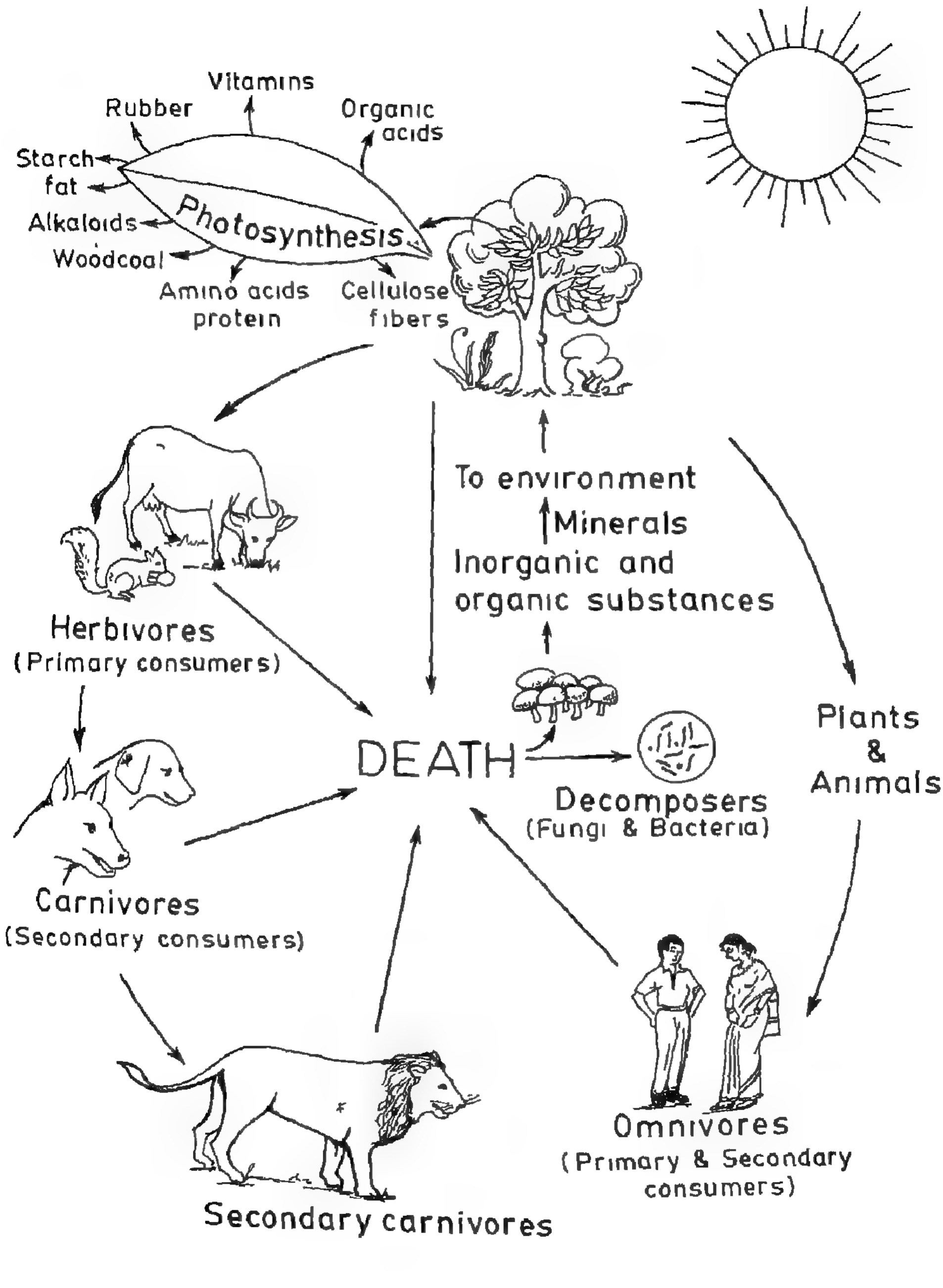


Fig. 13-9 Food chain green plants are a chief source of food for all herbivores which in turn are consumed by primary and secondary carnivores whereas omnivores depend both on plants and animals, microorganisms decompose dead plant and animal matter and make nutrients available for plant growth

Potassium Although it does not enter into the composition of any organic compound, it probably provides the necessary factors to carry out metabolism in the cell This is so because it is required in large quantities Deficiency of potassium causes death of young shoots and leaves and a decrease in protein synthesis

MICRONUTRIENTS

In addition to the macronutrients, there are other elements which are needed in very small quantities but play major roles. These may consist entirely or partly of metallic elements (iron, copper, manganese, zinc, molybdenum) Minor elements are essential for catalytic reactions in the cell, e g , iron is a component of many important respiratory enzymes Its absence results in chlorosis of the entire plant or a single branch. Copper is also a part of certain enzymes It is highly toxic, and is needed in very small quantities. Manganese is believed to be a specific activator of enzymes Its absence results in the accumulation of nitrite, the leaves show symptoms of nitrogen deficiency, and appear mottled. Zinc is an activator of a group of enzymes and certain growth hormones. Mottled leaves appear in walnut, apple, citrus and other fruit trees when it is deficient Molybdenum is involved with enzymes that reduce nitrates to ammonia. In its absence, nitrates may accumulate in the plants, protein synthesis may be blocked and plant growth may stop. Boron is absorbed as borate ions It is supposed to play an important role in carbohydrate and fat metabolism. Death of meristematic cells results from its deficiency

The plants need some other elements than what are described above. Some of them are indispensable for plant growth and are absorbed in minute quantities from the soil For example, silicon is responsible for the stiffness of the straw of cereals, which probably also increases their resistance to the attack of fungi and insects. Experimental evidences indicate that if the above macro- and microelements are supplied in appropriate quantities, the plants remain healthy

The vigorous growth of the plants depends upon proper soil conditions, including its physical (pH, pore size, etc) and chemical (presence of mineral salts) status. This is why fertilizers are regularly added to the soil to maintain a proper balance of nutrients.

Other Modes of Nutrition

All organisms need a regular supply of element to sustain their growth and meet energy requirements The green plants are autotrophic, i.e , they manufacture their own food from simple inorganic materials in the presence of sunlight On the other hand, the bacteria, viruses, fungi, and a few specialized non-green flowering plants derive their nourishment and energy from complex organic substances available in the environment. Such a mode of nutrition which involves dependence on preformed organic substances is termed heterotrophism

The heterotrophic organisms are commonly of three types—saprophytic, parasitic and symbiotic The saprophytes live on dead bodies or organic remains of plants and animals, food products, excrements, and so on The parasites, however, thrive on or inside another living organism which is designated as the host. They obtain their nourishment from the host and may damage or even kill it in this process. The symbiotic organisms are, however, mutually dependent on each other for their nutrition

SAPROPHYTES

Many bacteria and fungi have a saprophytic mode of nutrition. They decompose dead organic matter. Because of this activity they are of great economic importance Many are beneficial as scavengers in nature as they clear our environment of the remains of dead plants and animals and release their inorganic constituents for reuse However, others are harmful as they spoil the foodstuffs and bring about decay

of timber, leather, etc.

The saprophytic mode of nutrition may be exemplified by the common bread mold *Rhizopus* It cannot absorb large starch molecules directly and, therefore, first converts them into smaller soluble molecules with the help of the starch digesting enzyme, amylase The enzyme is secreted out and digestion occurs extracellularly The sugar molecules produced are subsequently absorbed by the mould

PARASITES

Many bacteria, viruses, fungi, a couple of non-chlorophyllous flowering plants and a host of animals are parasitic as they obtain their food from other living organisms. It is for this reason that parasitic bacteria, viruses and fungi cause several diseases. The fungus *Albugo candida* is

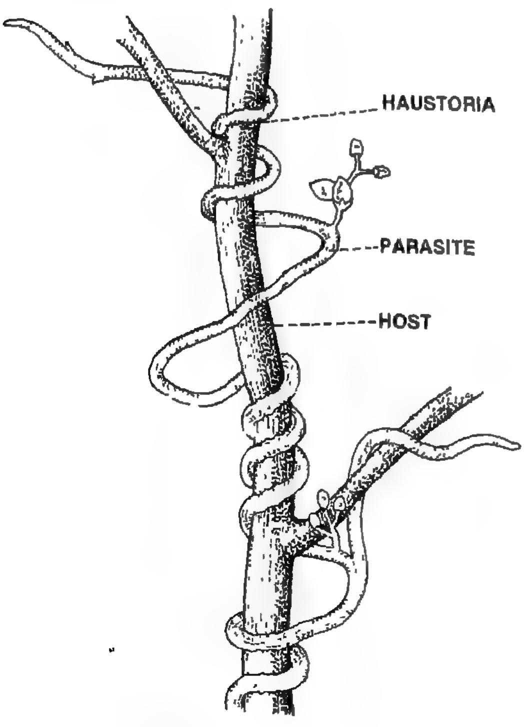


Fig. 13-10 *Cuscuta reflexa* (total parasite) twining around stem of host

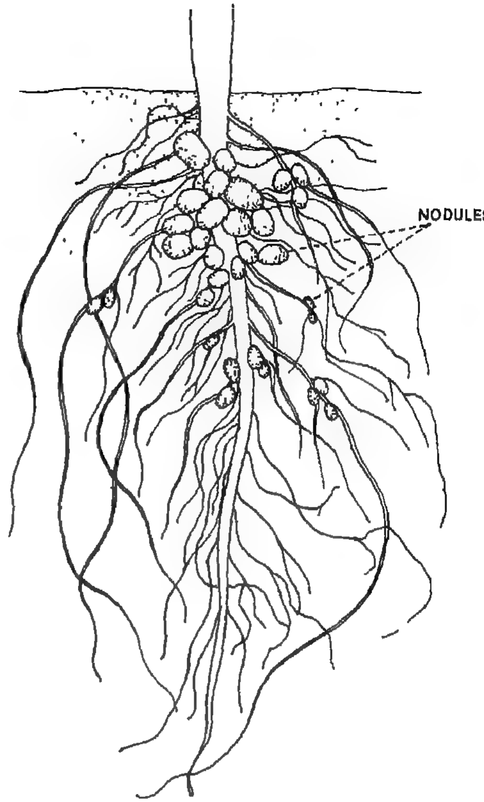


Fig 13-11 Portion of leguminous root bearing bacterial nodules

parasitic on some higher plants The mycelium of this fungus is coenocytic and composed of hyphae which grow intercellularly into the host tissue These hyphae produce short knob-like haustoria into the host cells which enzymatically digest and absorb food from the host tissue

Among higher plants only a few species have specialized as parasites Examples are *Cuscuta, Orobanche* and *Viscum*. *Cuscuta* or dodder, which grows as parasite on shrubs and trees, lacks leaves and chlorophyll (Fig 13-10) However, its roots are modified as haustoria which penetrate the stem tissues of the host and establish direct contact with its vascular tissues. Since dodder plants do not photosynthesize, their leaves have been completely lost during evolution. Such a

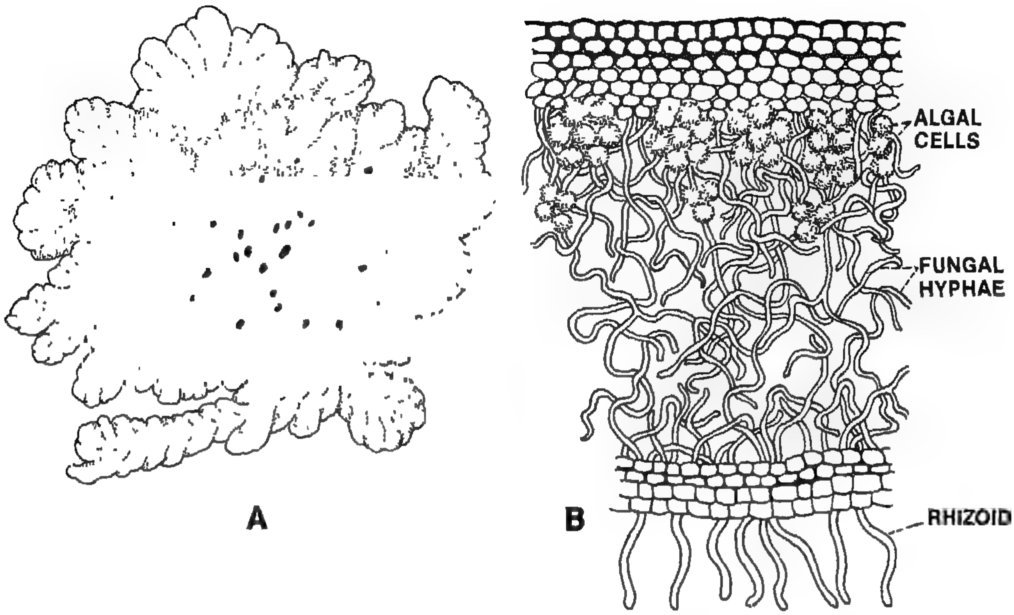


Fig 13-12 Foliose lichen (A), section through thallus showing algal cells embedded in fungal mycelium (B)

loss of unwanted structures and functions is a usual characteristic of all parasites.

SYMBIONTS

You have already learnt of the nitrogen fixing capability of the blue-green algae. Some of these, such as *Nostoc* and *Anabaena*, live in the cells of the leaves of *Azolla* This fern supplies the alga with organic substances, whereas the alga provides nitrogen to the fern A similar, mutually beneficial relationship between the legumes and *Rhizobium* (Fig 13-11), is also well known In legume root-nodule symbiosis, the legume is the bigger partner and the *Rhizobium* the smaller, and is referred to as a microsymbiont.

Another common group of symbionts are the lichens (Fig. 13-12A) These curious plants generally grow on rocks, barks of trees, rotting wood or soil They exhibit an intimate association of an alga (phycobiont) with a fungus (mycobiont) In this close biological union of two dissimilar organisms (Fig. 13-12B), the alga obtains minerals, water and nitrogen from the fungus, whereas the fungus receives the carbohydrates from the alga

Some Useful Terms

Autotroph An organism capable of synthesizing its required nutrients from simple organic and inorganic substances

Biosphere All those parts of the universe—air, water, and soil which are capable of supporting life

Biosynthesis The process of formation of a chemical substance by a living cell or an extract of a living cell

Carnivore A flesh-eating animal, commonly referred to mammals of the order Carnivora

Carotenoid A group of yellow, orange and red plant pigment, found mostly in plastids and also in some animal tissue

Chlorosis An unhealthy condition of the plants showing yellowing due to deficiency of chlorophyll

Coenocytic A multinucleate condition in plants in which there are many nuclei in a continuous cytoplasm

Covalent Bond A chemical bond between two atoms which is formed by sharing electrons

Fertilizer Any chemical substance which when applied to the soil increases its nutrient content, or adjusts its acidity and alkalinity, thus promoting plant growth

Fluorescence Emission of light, usually visible, of wave length different from that absorbed from irradiated materials, or from impact of electrons

Food Chain A series of organisms starting from plants in which one organism provides food for the other successively

Herbivore An animal that lives mainly on plants

Heterotroph An organism that cannot synthesize its own organic nutritive substances and must feed on nutrients manufactured by autotrophs

High Energy Bond A chemical bond between two atoms of a complex compound which releases a large amount of energy on being broken

Macronutrient Any element or compound which is required in a relatively large quantity by living organisms

Micronutrient Any element or its compound which is needed only in a small quantity by living organisms

Nicotine Adenine-Dinucleotide Phosphate (NADP) A complex organic compound which helps in the transfer of hydrogen in the hydrogen transport chain before the latter combines with oxygen to form water during cellular respiration

Nutrient The elements and compounds which provide the food requirements of plants and animals

Omnivore An animal that feeds on both plants and animals

Parasite An organism that lives in or on an organism of a different species and derives nourishment from it

Photophosphorylation The process of addition of a phosphate group to ADP to form ATP using light energy

Pollution Contamination of air, water, and soil by waste substances or by any other environmental factor which make it harmful or unpleasant to life

Quantum Indivisible unit of any form of physical energy, particularly the photons

Saprophyte A plant which obtains its nourishment from dead organic matter

Scavenger An organism that feeds on dead organism or the wastes of organisms

Symbiosis A close association of two or more dissimilar organisms from which each partner benefits

Things to Do

1. Boil a few green leaves in water and then decolourize them in 95% ethyl alcohol by keeping the container in water bath Take the leaves out and pour dilute potassium iodide solution The intensity of colour will indicate the amount of starch synthesized. Leaves of plants growing in light and dark can also be tested

2. Select leaves of variegated plants such as *Coleus*, and *Croton* Bleach them in 95% ethyl alcohol (as in Experiment 1) and test them for starch. Non-green areas (without chlorophyll) will not give blue colour with iodine solution

3. Germinate a few seeds and place the seedlings in the dark Observe the growth of the plants and see what happens to the new leaves Transfer the seedlings to light after a couple of days in dark and interpret the changes

4. Keep a potted dicotyledonous plant in dark for 24 hours to destarch the leaves Cover a portion of a leaf with light screen or black paper with the help of a clamp. Now expose the plant to sunlight. Pluck the leaf after 4 hours and remove the screen After decolourizing in 95% ethyl alcohol, test the leaf for starch The covered area will remain yellow because no photosynthesis occurred as light was not available

5. In boiled and pre-cooled distilled water, dissolve minute quantity of indigo carmine. Decolourize the solution by adding carefully small amounts of sodium hydrosulphite ($Na_2S_2O_4$) Put a few *Hydrilla* twigs in the mixture and make the container airtight Keep the set-up in sunlight After some time the solution becomes blue This is because indigo carmine which was reduced to colourless form by $Na_2S_2O_4$ is oxidized back to its original colour due to the release of O_2 from *Hydrilla* twigs

6 Place a few healthy *Hydrilla* twigs with their cut-ends upwards in a beaker filled with water Place an inverted [illegible] the twigs. Invert a water-filled test tube over the stem of the funnel Gas bubbles [illegible] ds of twigs will replace water at the top of the test tube The gas thus collected can be tested. By counting the number of bubbles in relation to time, you can determine the rate of photosynthesis

7 Keep a potted plant with variegated leaves in dark for 24 hours Take a wide-mouthed bottle fitted with a split cork Place a small amount of 20% KOH solution in the bottle Insert half portion of a healthy leaf of the above plant into the bottle through the split cork Make the bottle airtight Keep the entire set-up in light After about 24 hours, remove the leaf and bleach with alcohol (as in the previous experiment) Test the decolourized leaf for starch and interpret your observations

8 Germinate a few seeds of corn, tomato, sunflower or oat on moist filter paper or cotton wool. Plant individual seedlings in water, in a mineral nutrient medium containing all essential elements and in mineral solution lacking adequate quantities of some essential element Examine the plants every few days and observe changes in such features as colour, amount of growth in roots, and of shoots Correlate the growth of plant with the mineral solution lacking a particular essential element on the basis of the deficiency symptoms attributed to a particular missing element.

9 Take a piece of moist leather or bread and leave it exposed for 2 or 3 days Study the cottony growth under the microscope Can the organisms constituting it be classified under saprophytes?

10 Observe a parasitic flowering plant such as *Cuscuta* growing on a host. List the characteristics of the parasite and the mode of nutrition

11 Moisten three pieces of bread by sprinkling a few drops of water on them. Keep one piece in the refrigerator. Wrap the second piece with wax paper and keep it at room temperature. Leave the third piece unwrapped in your room Watch the differences in the three pieces after 2 or 3 days and explain your observations.

12 Crush the nodules of a leguminous root on a glass slide Make a smear mount Stain it with a drop of crystal violet (4%), wash with water and add a drop of iodine Identify the presence of bacteria under a microscope after washing the smear with rectified spirit.

Test Yourself

1 Tick (✓) the correct answer:

(a) ATP is formed during
  (i) dark reaction of photosynthesis
  (ii) photophosphorylation
  (iii) Hill reaction
  (iv) absorption of solar energy by chlorophyll

(b) The following is not a micronutrient:
  (i) zinc
  (ii) phosphorus
  (iii) boron
  (iv) copper

2 Distinguish between.
(a) photosynthesis and photophosphorylation
(b) C_3 cycle and C_4 cycle
(c) Hill reaction and NADP reduction in chloroplast

3 State the functions of the following elements.
(a) calcium
(b) manganese

(c) phosphorus
(d) nitrogen

4 State the deficiency symptoms of
(a) magnesium
(b) potassium
(c) boron

5 Fill in the blanks.
(a) Nitrogen is a _________.
(b) Green plants are called_________because they manufacture their own food.
(c) The light absorbing pigments of chloroplast are _________ and _________.
(d) The solar energy is converted into _________ energy during photosynthesis.
(e) The energy-rich compound generated during photosynthesis is ___________

6 Classify the following plants by their mode of nutrition
(a) bacteria (b) dodder (c) lichen (d) wheat (e) mushroom

Try to Answer

1 Is photosynthesis the only process for ATP (chemical energy) formation? Explain.

2 When do you expect an increase in the rate of photosynthesis—in green, red or blue light? Comment

3 If a green plant is placed in air free of O_2, would it live longer in light or in darkness?

4 Trace the fate of a molecule of water after it reaches the mesophyll cells

5 Will the rate of photosynthesis increase if a *Hydrilla* plant is kept in a bottle of Campa Cola?

6 Considering that CO_2 is essential for photosynthesis, how do the aquatic green plants survive?

7 Technically speaking, is chloroplast or the chlorophyll more important for photosynthesis.

8 Water is used as well as produced in the process of photosynthesis. Comment

9 Make some recommendations to the farmer to increase the rate of photosynthesis in a field of wheat/corn/rice

10 Would you prefer to feed minerals to the plant through leaf or through root and why?

11 Can the addition of calcium carbonate to the soil improve the growth of the plants? How?

12 In spite of the presence of all the essential elements in the soil, the plants sometimes show symptoms of mineral deficiency Explain.

13 Plants usually show better growth when ammonium sulphate is added to the soil How would you explain this behaviour?

14 What would happen if all the parasites were completely destroyed from this earth?

15 Differentiate between symbiosis and mutualism

16 In summer food gets spoilt much quicker than in winter True or false? Give reasons to support your answer.

17 Distinguish between the modes of nutrition in the following and state as to how they are interrelated green plant, mammal, mould, lichen.

18 List some practices which can upset the biological balance in nature

14

Animal Nutrition

Modes of nutrition, Nutrients, Liquid feeders, Particle feeders, Digestion, Absorption, Assimilation, Egestion

ALL ANIMALS REQUIRE food in order to stay alive, to obtain energy or to grow Whereas most of the plants are autotrophs, i.e., they synthesize the organic constituents of their food from inorganic substances, almost all the animals are heterotrophs They do not manufacture their food but depend for their nutrition either on plants (herbivores) or on other animals (carnivores or predators), or on both (omnivores). Very few of the animals, e.g., the protozoans—*Euglena, Volvox*—which contain chlorophyll, have retained autotrophic mode of nutrition as well (that is why these are also included in the plant kingdom) The heterotrophs are mostly free living and have holozoic mode of nutrition, i.e., feed on solid organic matter. Some of the heterotrophs live either on (ectoparasites—body louse, bed bug) or inside (endoparasites—tapeworm, roundworm) another organism, the host, and have ectoparasitic or endoparasitic mode of nutrition, respectively. They generally take liquid organic food from their host. A few other animals, e.g , the protozoans—*Mastigamoeba, Chilomonas*—have saprozoic mode of nutrition. They absorb dead organic matter (rendered in the form of solution) by osmosis through their body surface.

The nutrients required by a vast majority of animals are essentially similar. Among the organic constituents, the carbohydrates and fats are essential, primarily for energy. The proteins help in growth, tissue repair and synthesis of body secretions, besides being a source of energy. Certain amino acids needed by the animals can be synthesized by them, those which cannot be, must be taken in the food The vitamins participate in a number of biochemical reactions in the body and are necessary for normal growth and metabolism The animals also require water and many inorganic substances. The phosphates and chlorides of sodium, potassium, calcium, magnesium and iron are needed in large quantities. The iodides and fluorides of zinc, copper, manganese and cobalt suffice only in traces. The inorganic substances usually form an integral part of tissues, act as catalysts or take part in several metabolic reactions.

Feeding Mechanisms

There are various mechanisms by which the animals obtain their food The mode of feeding depends on the nature of food which may be in the form of liquid, small or large particles, an en-

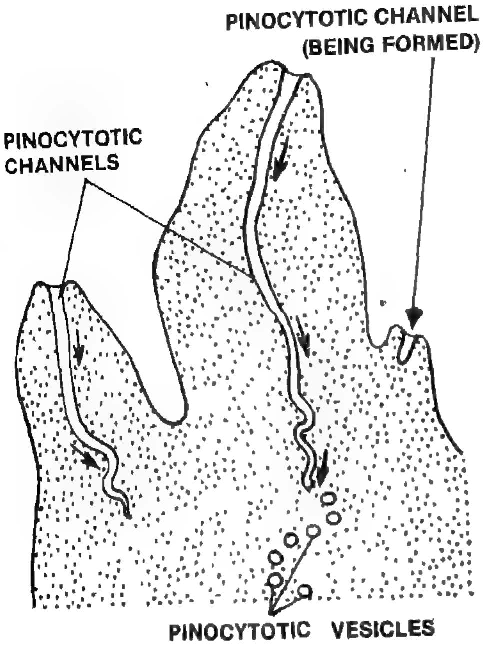


Fig 14-1 Magnified view of portion of *Amoeba* showing pinocytosis

The liquid feeders adopt the following methods:

Diffusion In many protozoan parasites and tapeworms, the dissolved organic matter in their surroundings is absorbed through their body surface. This is referred to as diffusion

Pinocytosis It is the process of taking in droplets of dissolved food into a cell by invaginating the cell membrane to form a vesicle which is then pinched off at the tip and migrates into the interior of the cell as in *Amoeba* (Fig 14-1)

Suction The leeches cut the body surface of cattle or man to suck blood. The mosquitoes and bugs pierce their mouth parts into plants to suck the juices, or into animals to draw the blood.

The particle feeders are classified as follows on the basis of the size of the food particles consumed·

1 Microphagous animals They feed on particles too small to be captured individually They possess different kinds of filtering devices (clusters of pseudopodia, cilia or flagella in some protozoans and sponges, sheets of mucus in many snails, groups of setae in a number of crustaceans), and, therefore, their method of food intake is referred to as filter-feeding As water passes through the filters, the contained particles of food and other materials are retained.

2 Macrophagous animals They consume particles large enough to be captured individually For example, *Amoeba* catches and engulfs its prey by means of pseudopodia, the mechanism being called phagocytosis. The earthworm extends its buccal chamber to pick up particles of soil and to procure nutrients present therein The coelenterates generally grab other organisms by their tentacles and transfer them to the mouth. Most of the fishes, amphibians, reptiles and birds get hold of their food by jaws, tongue or beak and ingest it without chewing. Special structures for seizing and masticating, viz., those concerned with biting, rasping, grazing, are present in other

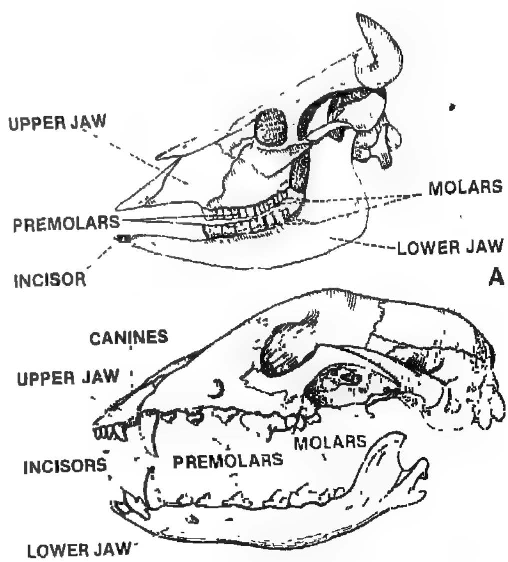


Fig 14-2 Skull and lower jaw of herbivore—ox (A) and carnivore—dog (B)

animals. The snails, cuttle fishes and octopuses use their arms beset with suckers. The arthropods employ cephalic or thoracic appendages Some birds have clawed feet for the purpose. The food captured by most of the mammals is masticated before being swallowed. Their teeth as well as jaw bones (Fig. 14-2) and muscles are specially developed for efficient mastication In herbivores, the premolars and molars have predominant ridges on the crowns for effective grinding The carnivores, however, have large and sharp canines for tearing the flesh of the prey.

Digestion of Food

The food consumed by the animals generally needs to be digested, i e , transformed into simpler constituents in order to get utilized by them. Although the process varies in different animals, it essentially involves mechanical and chemical breakdown of food and is described here with reference to mammals

(The food chewed by mammals is broken into small bits and is acted upon by the enzymes secreted into the mouth and the alimentary canal. The complex carbohydrates present in the food are digested by carbohydrases (amylase, maltase, lactase, sucrase) The proteins are split by proteinases (pepsin, rennin, trypsin, chymotrypsin, peptidases) The fats and lipids are broken down by lipases) Among the digestive enzymes, carbohydrases dominate in the digestive tract of herbivores, proteases in that of carnivores, whereas all groups of enzymes are more or less equally distributed in omnivorous species

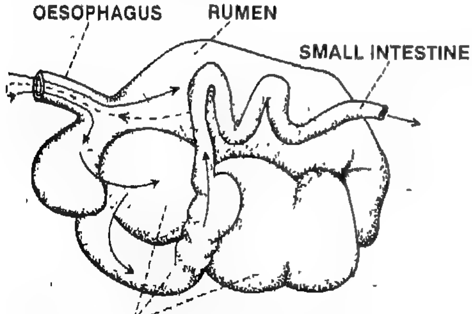


Fig. 14-3 Ruminant stomach of cow (arrows indicate direction of movement of food)

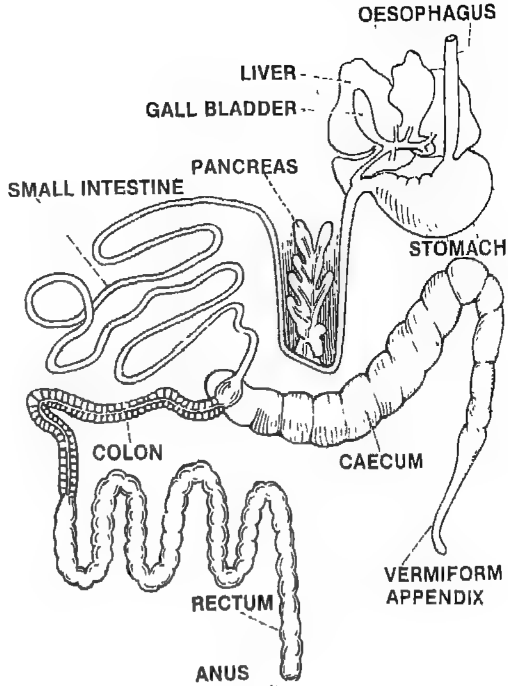


Fig 14-4 Digestive system of rabbit showing caecum

Carbohydrates In the herbivores, the salivary glands secrete large quantities of saliva into the mouth. Amylase present in it helps in the digestion of starch. Cattle, sheep and goats swallow improperly chewed food and store it in the rumen, a large chamber of the stomach (Fig. 14-3) Millions of bacteria and ciliate protozoans present in it ferment the food The enzyme cellulase produced by them breaks down cellulose which is abundant in the food The major part of the ingested material is then passed back to the mouth as cud and thoroughly chewed and mixed with saliva for further digestion. Horses, rabbits

and hares lack rumen but degrade cellulose with the help of symbiotic microorganisms present mainly in the caecum (a diverticulum of the large intestine; Fig 14-4) Some of the carnivores, e g., dogs and cats, lack amylase in their saliva. As the food passes down the intestine, several enzymes such as amylase, maltase, lactase and sucrase delivered from the pancreas or the intestine, convert the complex carbohydrates into simple sugars

Proteins As the food passes into the stomach, it is acted upon by gastric juice, rich in hydrochloric acid and the enzymes pepsin and rennin Pepsin acts in an acidic medium and converts proteins into peptones The activity of pepsin is much higher in carnivores than in herbivores. Rennin curdles milk proteins for hydrolysis by pepsin Further digestion of proteins and their partially digested products into simple peptides and then into amino acids is brought about in an alkaline medium in the small intestine The enzymes which carry on this task are trypsin, chymotrypsin and exopeptidases released from the pancreas and the peptidases from the intestine.

Fats The acidic food passing from the stomach into the intestine is mixed with bile released from the liver The bile makes the food alkaline and emulsifies fats. The emulsified fats are then acted upon by lipase delivered from the pancreas, and converted into simple glycerides, free glycerol and fatty acids. In cattle, the fats also are broken down by bacteria present in the rumen.

Absorption

The digested food and water are absorbed mainly in the small intestine Its epithelial lining is thrown into a number of folds called villi (Fig 14-5) which greatly increase its absorptive surface. The villi have a rich supply of blood capillaries. Simple sugars and amino acids are absorbed through the intestinal wall into the blood capillaries These are then carried by the portal vein to the liver before release into general circulation. The glycerides and fatty acids are

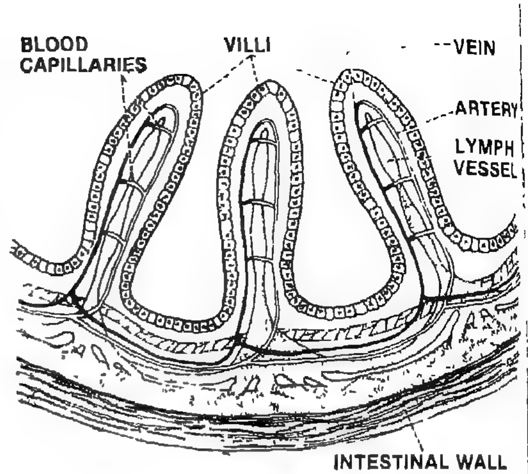


Fig 14-5 Villi in the intestine of mammal

transported usually via the lymph vessels and the thoracic duct to the blood

Absorption in the stomach occurs only to a limited extent Small amounts of water and alcohol may be carried across its wall The large intestine absorbs much of the residual water from the undigested food which passes through it

Assimilation

The body utilizes the absorbed food materials in various ways The simple sugars (e.g., glucose) provide energy, the excess amount is converted into glycogen with the help of enzymes in the liver and deposited therein This glycogen may be reconverted into glucose depending upon the needs of the body, and released into the blood stream. The amino acids may be utilized for the synthesis of a variety of proteins and nitrogenous substances (purine, pyrimidine) required by the body. The breakdown of amino acids yields ammonia which is converted into urea in the liver and excreted through the kidneys The glycerol and fatty acids may take part in various metabolic reactions or are reconverted into fats. These accumulate in fat depots below the skin or around various organs. Extra fats may be changed into carbohydrates in the liver and retained for future use.

Egestion

The undigested food, along with various secretions and sloughed-off epithelial cells from the alimentary canal, pass into rectum and constitute the faeces A large number of intestinal microorganisms, their fermentation and putrefaction products and water are also present in the faeces It may be coarse, fibrous or fine particulate depending upon the nature of diet. The accumulation of faeces distends the rectum, a defecation reflex contracts it and voids the faecal matter through the anus

Some Useful Terms

✓**Bile** *A secretion of the liver, stored in gall bladder, helps in emulsification of fat*

Chymotrypsin The proteolytic enzyme produced by pancreas, which hydrolyzes peptide bonds in alkaline medium

Egestion Discharge of undigested and unabsorbed material from alimentary canal

Exopeptidase An enzyme which helps in the hydrolysis of peptide bonds adjacent to free amino (—NH2) or carboxyl (—COOH) groups

Glycerides Esters of fatty acids with glycerol

Holozoic Organisms feeding on solid organic matter

Ingest To eat, to take food into the body or alimentary canal

Lipase A fat-digesting enzyme

Lymph Vessel Thin closed vessels which help in circulating lymph

Macrophagous Organisms feeding on relatively large particles of food

Masticate To reduce solid food to fine state of subdivision or to pulp

Microphagous Organisms feeding on very small particles of food

Protease Any protein-splitting enzyme

Rennin An enzyme found in gastric juice, which causes curdling of milk

Saprozoic Organisms which absorb dead organic matter as solution through body surface

Urea A compound formed as a nitrogenous waste product of metabolism and found in urine; used as nitrogen fertilizer

Things to Do

1 Obtain samples of pond water containing *Amoeba, Paramoecium,* and *Hydra.* Examine their modes of capturing food. Record the movements of their pseudopodia *(Amoeba)*, cilia *(Paramoecium)*, or tentacles *(Hydra)*.

2 Note the shapes of teeth in the upper and lower jaws of a goat and a dog from their skeletons in the school museum Correlate them with the feeding habits of the animals

3 Procure goat's stomach from a butcher's shop Examine its various compartments and identify the rumen.

Test Yourself

1 Explain the following modes of nutrition In which animals do they occur?
(a) autotrophic (b) holozoic (c) saprozoic

2 Fill in the blanks
(a) The________teeth are well developed in carnivorous mammals
(b) *Amoeba* ingests its food by the process of pseudopodia

Proteases

(c) The proteins are digested by a group of enzymes called ~~[illegible]~~, and fats by lipases.

(d) Pepsin acts in an acidic medium whereas trypsin acts in an ______ medium.

3 Distinguish between:

(a) microphagous and macrophagous animals

(b) ingestion and digestion

(c) absorption and assimilation

(d) diffusion and pinocytosis

4 What is the difference in the digestive processes of herbivorous and carnivorous mammals

5 Which inorganic substances are required by man in large quantities?

6 State the functions of the following:
(a) molars (b) rennin (c) bile (d) saliva

7 Can you digest cellulose? If not, why?

Try to Answer

1 Why do animals require different types of nutrients?

2 What is the advantage of filter-feeding in animals?

3 Clasify the following on the basis of their feeding mechanisms spider, cockroach, wasp, malarial parasite, roundworm, head louse, prawn.

4 Indicate the changes which the following will undergo in your digestive tract: roast chicken, butter toast, milk, banana, glucose

5 The stomach of a patient had to be removed on medical grounds What special diet would you recommend for him and why?

6 If a major part of the small intestine of a man has been removed, will this affect absorption of food?

7 What digestive disorders do you expect in a habitual alcoholic?

8 Fatty diet is not advised for persons suffering from jaundice or diarrhoea. Explain why?

9 Why does the administration of antibiotics often lead to digestive disturbances?

10 Compare the nutrients needed by plants and animals

15

Respiration

Breathing, Gas exchange, Respiratory organs, Inspiration, Expiration, Glycolysis, Oxidative phosphorylation, Citric acid cycle, Anaerobiosis, Fermentation, Factors, Combustion

FOR THOUSANDS of years man has looked upon breathing as a sure sign of life. Even in the event of suffocation and drowning artificial respiration is resorted to immediately in the hope of saving life by restoring the person's ability to breathe. Thus, breathing is one of the very important aspects of respiration It is obligatory for all plants and animals to respire but all of them may not breathe For example, trees, amoebae, sponges and earthworms respire, but they do not breathe Frogs, lizards, birds and all mammals including man respire as well as breathe. Breathing is referred to as a mechanical process of taking in atmospheric air into the respiratory organs, say lungs, and giving out carbon dioxide from them. The oxygen that is inhaled with the atmospheric air performs a very vital function It is utilized to oxidize completely the nutrients, viz., glucose, fatty acids and amino acids producing carbon dioxide, water and energy This latter aspect of respiration is referred to as internal respiration, or tissue or cell respiration. The chemical energy so generated is put to use to carry out the various activities that are characteristic of the living state. On the other hand, the mere exchange of gases between the lung and blood is called external respiration

Process of Gas Exchange

All living things respire. As a result there is an exchange of gases between the cell and its environment. The cell obtains oxygen from the environment and returns carbon dioxide and water vapour to it It is essential that the membrane through which the gases diffuse should be moist.

FLOWERING PLANTS

Unlike the majority of animals, in plants the atmospheric air moves in and out by simple diffusion, through the stomata of the leaves and the surface tissues in general. Subsequently, the gases enter the intercellular spaces Oxygen is absorbed by the individual cells for use in energy-yielding reactions. As oxygen is utilized, more of it diffuses into the plant to take its place. Since carbon dioxide is being continuously formed, its concentration in tissue spaces becomes higher than in the surrounding air Consequently, it diffuses out of plant, especially if it is not being used for photosynthesis

Besides leaves, other parts of the plant, such as stems, roots, fruits and seeds, also respire. The respiratory rates of root and shoot apices, and germinating seeds are, however, higher since they

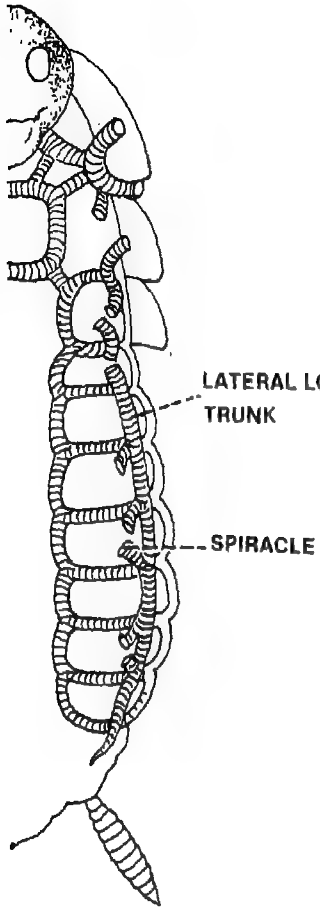


Fig 15-1 Tracheal arrangement in cockroach (dorsal view)

are actively growing and, therefore, require much more energy.

PROTOZOANS

Amoeba represents a simple aerobic protozoan. It requires a constant supply of oxygen to produce energy for performing its essential normal activites. Like any other aquatic organism, it makes use of oxygen dissolved in water. The concentration of oxygen is far less inside the body of amoeba than in the surrounding water and, therefore, oxygen readily diffuses in through the plasmalemma. As a result of continuous catabolic activity inside amoeba, carbon dioxide produced is at a higher concentration than in the external medium so that it moves out through the plasma membrane.

INSECTS

Majority of insects respire by means of internal tubes called tracheae. These tubes branch extensively and carry air directly to the tissues. The tracheae open to the exterior by paired apertures called spiracles (Fig. 15-1). They lie laterally in the thoracic and abdominal segments. The spiracles lead into short tubes which, in turn, are connected with two large longitudinal tracheal trunks. Finer branches known as tracheoles that are given off from these tracheal trunks eventually penetrate the tissues. It is noteworthy that in insects there is no oxygen carrier, instead oxygen is taken directly to the tissues. The thin walls of the tracheoles permit the diffusion of respiratory gases. As the oxygen concentration is high in the air brought in, it diffuses readily into the tissues. The carbon dioxide concentration being high in the tissues, it diffuses out into the tracheoles and is then expelled with the air through the spiracles. The inflow and outflow of air are affected by the alternate contraction and expansion of the abdomen.

FISH

Gills are the respiratory organs in a fish (Fig. 15-2A). On removing the gill cover, called operculum, of a bony fish, one can see four gill arches—each carrying on its outer side, a double row of gill filaments. This, in turn, bears laterally, a row of respiratory leaflets, the gill lamellae (Fig. 15-2B). These are invested with upper and lower layers composed of thin flat squamous epithelial cells (Fig. 15-2C). A network of blood capillaries extends between the respiratory epithelial layers. Gases are exchanged between the blood circulating the gill lamellae and water surrounding them. Water is sucked in through the mouth by

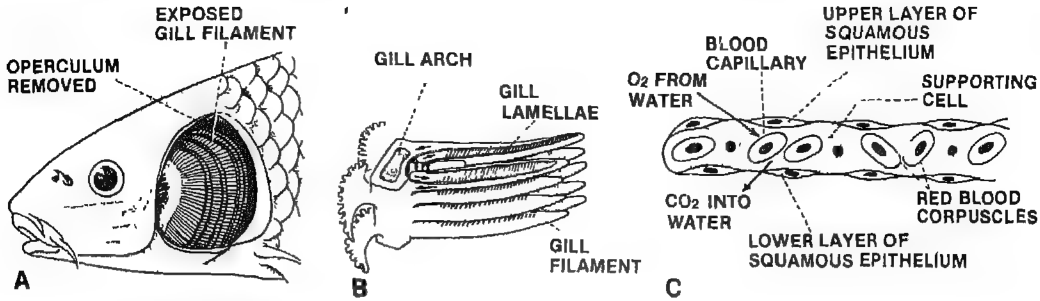


Fig 15-2 Lateral view of head of fish showing position of gills (A), structure of gills (B), and magnified view of gill lamellae (C), gaseous exchange between surrounding water and blood capillaries through respiratory epithelium is also shown in C

expansion of the buccal cavity It then flows into the opercular cavity by outward movement of the operculum. The dissolved oxygen from the surrounding water readily diffuses into the blood through the flattened epithelial cells lining the respiratory leaflets. This happens when deoxygenated blood with a low oxygen concentration flows through the capillaries. Conversely, carbon dioxide with a high concentration in the blood also diffuses out through the gill lamellae Water is then expelled via the opercular openings by inward movement of the operculum.

MAN

One of the immediate needs of larger animals including man with high rates of oxygen consumption is to obtain enough of it to sustain life. This requirement is met with by the lungs that provide huge surface area for the exchange of gases The lungs are located in the thorax Each lung consists of a tree-like system of branched tubes (Fig 15-3A) The finest of these branches terminate into millions of tiny sac-like structures called alveoli Their presence gives the lungs a sponge-like texture When magnified, a group of alveoli resembles a cluster of grapes (Fig. 15-3B) The two lungs contain approximately 700 million alveoli, giving a total surface area of over 70 square metres The delicate walls of the alveoli are made up of moist cells and are lined with a network of blood capillaries (Fig 15-3C) The walls

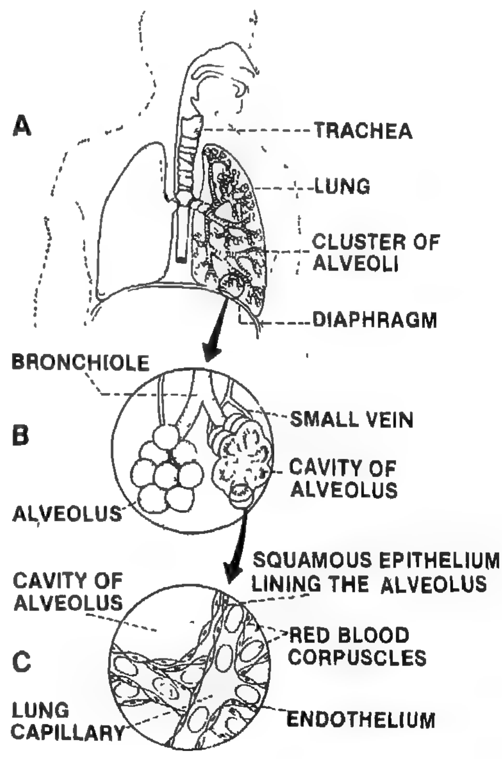


Fig 15-3 Respiratory tract of man (A), magnified view of a cluster of alveoli (B) and [illegible] between lung capillaries and [illegible] alveoli (C)

of the capillaries and alveoli both consist of a single layer of extremely thin, flattened, epithelial cells firmly attached to each other The

blood which flows to the lungs from the heart contains little oxygen and much carbon dioxide. On the other hand, the air in the alveoli has a high concentration of oxygen and relatively less carbon dioxide. Therefore, a two-way diffusion takes place through the cells of the capillaries Oxygen enters the blood and carbon dioxide leaves it. The exchange of gases is completed within a few seconds while the blood is passing through the alveoli This is made possible due to enormous surface of a lung exposed to the external environment

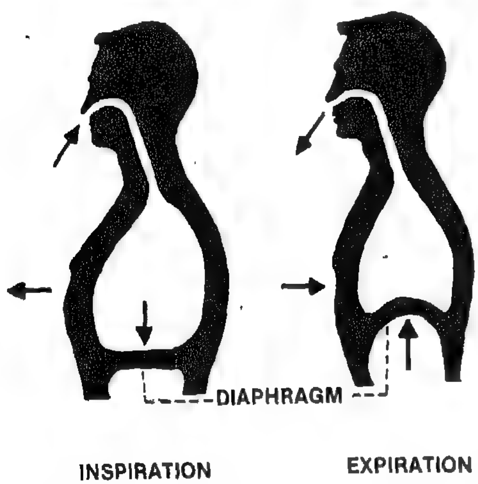


Fig 15-4 Breathing mechanism in human body Arrows indicate movements of chest wall and diaphragm during inspiration and expiration

Breathing Mechanism Functionally, the lungs are elastic bags somewhat similar to rubber balloons There are no muscles that allow them to expand by themselves. Instead, the lungs respond passively to pressure changes within the thoracic cavity (Fig 15-4) During the process of breathing in of air (inspiration), muscles between the ribs contract and lift the thoracic basket. At the same time the diaphragm (a muscular sheet separating the thorax from the abdomen) is drawn downward by muscular contractions The combined upward movement of the rib cage and downward motion of diaphragm increase the volume of chest cavity This sudden expansion acts like a suction device, drawing in air into the lungs Inspiration is followed by expiration (breathing out process) which is a relaxation of muscles controlling the ribs and the diaphragm. Consequently, the thorax is lowered and the diaphragm ascends to its original position forcing air, containing carbon dioxide, out of the lungs

Basic Mechanism of Respiration

The essence of respiration is the production of chemical energy in the form of adenosine triphosphate (ATP). Each ATP molecule consists of a nitrogenous base (adenine), attached to the pentose sugar (ribose), which is further linked to three phosphate bonds in succession The second and third phosphate bonds are energy rich In a vast majority of reactions operating in the body of an organism, the third phosphate bond invariably splits off and releases energy of the order of 7,300 calories This energy is then utilized to carry out the metabolic functions The energy is derived by the oxidation of nutrients such as glucose

GLYCOLYSIS

Whether or not oxygen is available in the cells, the breakdown of glucose or glycogen is initially always anaerobic. Glucose (6-carbon compound) first reacts with a molecule of ATP to be activated. It is then degraded through step-wise, enzymatically controlled, reactions to form two molecules of a 3-carbon compound called pyruvic acid (Fig. 15-5) This anaerobic breakdown of glucose to pyruvic acid is called glycolysis. During this process, two molecules of ATP are used up, whereas four are produced, so that there is a net gain of two ATP molecules

FATE OF PYRUVIC ACID IN AEROBIC RESPIRATION

If oxygen is available, pyruvic acid enters a mitochondrion where it is oxidized into a

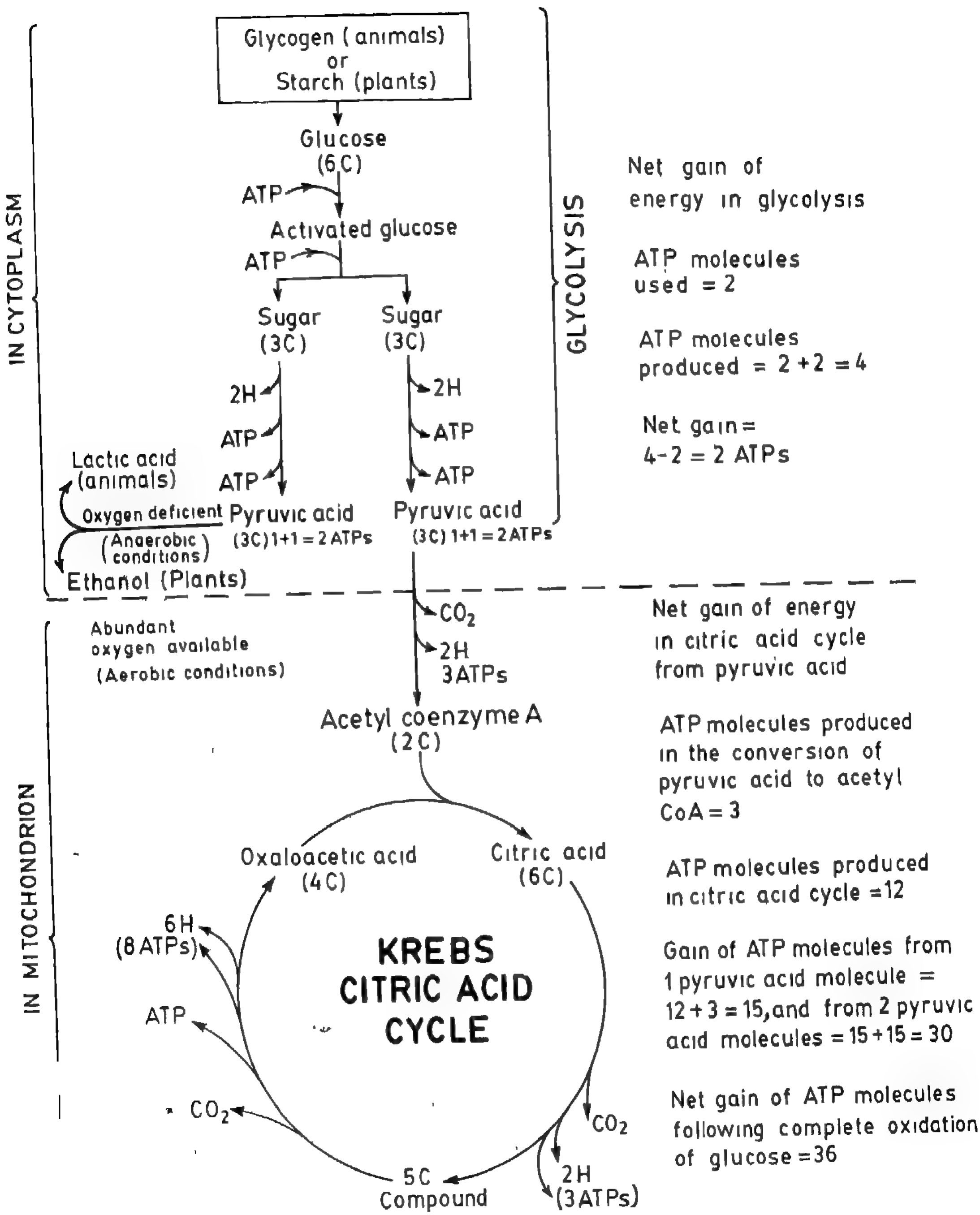


Fig 15.5 Production of energy in cells in anaerobic and aerobic respiration

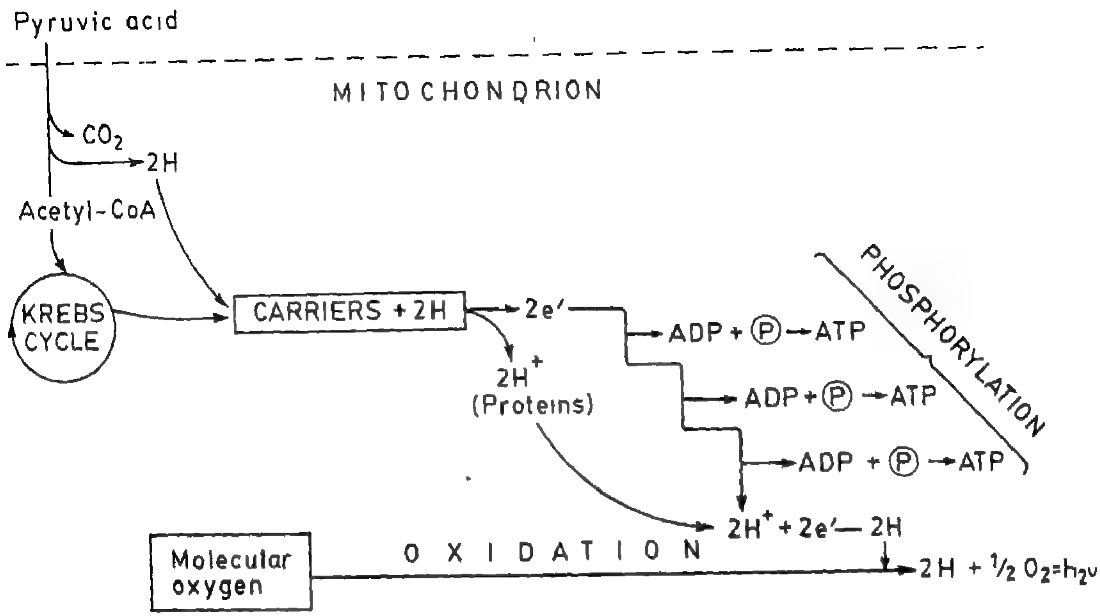


Fig 15-6 Steps in hydrogen carrier system leading to production of three molecules of ATP through oxidative phosphorylation

2-carbon derivative of acetic acid, called acetyl-coenzyme A (acetyl CoA) In this reaction, carbon dioxide is given off, and pyruvic acid loses two hydrogen atoms. Acetyl-CoA is an important intermediate compound in the breakdown of sugar It links glycolysis with the next series of reactions that are essentially energy-yielding. It is of interest that acetyl-CoA is also produced in the initial breakdown of fatty acids and amino acids

KREBS CITRIC ACID CYCLE

Acetyl-CoA (2-carbon) that is formed by the initial breakdown of glucose, condenses with oxaloacetic acid (4-carbon) to form citric acid (6-carbon) This reaction initiates the citric acid cycle It is then followed by a series of complex, enzymatically controlled chemical reactions, in which citric acid is gradually converted back to oxaloacetic acid in stages, via an important 5-carbon intermediate compound Sir Hans Krebs worked out this cyclical series of reactions which is, therefore, known as Krebs citric acid cycle. Two of the steps in the cycle involve the evolution and loss of carbon dioxide and four are concerned with the removal of hydrogen atoms (Fig 15-5). The specific organic compounds that carry hydrogen are derivatives of vitamin B-complex, and are designated as coenzymes The carrier system essentially consists of three different coenzymes and a series of coloured compounds called cytochromes. They act in a definite sequence to transport hydrogen (H^+ and e^-) The hydrogen atoms eventually combine with molecular oxygen to form water (Fig. 15-6) This mechanism of hydrogen transport is also known as electron transport chain or respiratory chain. It is accompanied by the coupling of ADP with phosphate forming three ATPs having energy-rich bonds. Since hydrogen transport involves oxidation as well as phosphorylation (ADP + P = ATP), this process by which cell system traps chemical energy is called oxidative phosphorylation

The aerobic breakdown of glucose is essentially an energy-yielding process. One molecule of

glucose after its complete oxidation generates 36 molecules of ATP in contrast to only two molecules of ATP formed in the anaerobic process of glycolysis (Fig 15-5).

SITES OF GLYCOLYSIS AND CITRIC ACID CYCLE

With the aid of certain biochemical techniques, it has been demonstrated that glycolysis operates in the cytoplasm The citric acid cycle, the transfer of hydrogen and electrons and oxidative phosphorylation are carried out in the mitochondrion. Thus mitochondrion is essentially the site of ATP manufacture (Fig 15-5)

ANAEROBIC RESPIRATION

Certain organisms, such as bacteria, yeast and some other fungi, derive energy by breaking down sugar in the complete absence of oxygen This process is called anaerobic respiration or anaerobiosis The organisms that can respire anaerobically are known as anaerobes These can be grouped under two categories: (i) complete anaerobes such as certain bacteria and intestinal flagellates of termites which live permanently in oxygen deficient conditions and are completely independent of oxygen for respiration; and (ii) partial anaerobes such as yeast, earthworm, cockroach and aquatic animals which flourish in the presence of oxygen but revert to anaerobic respiration if oxygen supply happens to be either deficient or even absent

In anaerobic respiration, sugar is not completely oxidized to carbon dioxide and water, but instead, it is partially split The initial breakdown of glucose is always anaerobic and it leads to the formation of pyruvic acid through glycolysis, in this respect it resembles aerobic respiration

Fate of Pyruvic Acid If oxygen supply is either deficient or absent, pyruvic acid follows either of the two pathways

(a) Pyruvic acid is reduced to lactic acid as would happen in an extremely active skeletal muscle during the course of heavy exercise The excess accumulation of lactic acid causes muscle fatigue Lactic acid that accumulates can be subsequently broken down or reconverted to carbohydrate when oxygen becomes available.

$$\underset{\text{Sugar}}{C_6H_{12}O_6} \xrightarrow{\text{Glycolysis}} \underset{\text{Pyruvic acid}}{CH_3\ CO\ COOH} \xrightarrow{+2H} \underset{\text{Lactic acid}}{CH_3\ CHOH\ COOH}$$

(b) Pyruvic acid is converted into ethanol via acetaldehyde, by yeast, *Saccharomyces cerevisae*. This process is also referred to as yeast fermentation. The fact that yeast can respire anaerobically to produce ethyl alcohol has long been used by man in breweries. Yeast is often mistakenly believed to be a complete anaerobe But in reality it grows much better in aerobic conditions. The secret in brewing is, therefore, not to let conditions become too anaerobic

$$\underset{\text{Sugar}}{C_6H_{12}O_6} \xrightarrow{\text{Glycolysis}} \underset{\text{Pyruvic acid}}{CH_3CO\ COOH} \xrightarrow{-CO_2} \underset{\text{Acetaldehyde}}{CH_3CHO} \xrightarrow{+2H} \underset{\text{Ethanol}}{CH_3CH_2\ OH}$$

Factors Affecting Respiration

In higher animals, the rate of respiration is influenced by the varying concentrations of carbon dioxide, oxygen and pH of the arterial blood A rise in carbon dioxide level of the blood, initiates faster breathing, with a greater volume of air moving in and out, till the carbon dioxide concentration gets back to the normal. An adequate amount of oxygen is required by neurons of the medulla oblongata and this oxygen controls the rate of respiration. If the neurons receive a deficient supply of oxygen, they become rather inactive Accordingly, they send fewer impulses to

respiratory muscles, thereby bringing down the pace of respiration It has been observed that a fall in blood pH enhances the rate of respiration Among other factors, changes in blood temperature, and exercise, speed up respiration A decrease is noticed as a result of unexpected pain stimulation, sudden cold stimuli, and excitation of the pharynx

Generally speaking, in plants, the factors, which affect photosynthesis also have a marked influence on the rate of respiration The activity of respiratory enzymes for catalyzing various reactions are among the most important internal factors. Water supply, temperature, and concentrations of oxygen and carbon dioxide constitute the chief external components. Respiration is very slow if the water content of the protoplast is low, as in dry mature seeds Temperatures beyond 50°C inactivate enzymes whereas those between 30 to 35°C are most congenial for respiration. Unless the oxygen level falls below 20 per cent, normal respiration can go on, however, anaerobic respiration can continue for some time even when the oxygen content is very low Respiration rate decreases if carbon dioxide is allowed to accumulate

Respiration versus Combustion

Although respiration produces heat, it does not cause a fire as we see during combustion. In other words, combustion constitutes a sudden explosive release of energy generating high temperatures like that of a fire, whereas respiration is controlled combustion. The major differences between the two are tabulated below·

Respiration	*Combustion*
1. It is a biological process and operates with the help of the cells of an organism	It is a non-life process and, therefore, noncellular.
2 It brings about the oxidation of organic molecules (e g , glucose) bond by bond, releasing energy in stages	It oxidizes the substrate (e.g , coal) rapidly, releasing the entire energy spontaneously
3. The chemical energy produced is either made available to the cell or stored in it as ATP	The energy is dissipated largely as heat, but can be harvested for useful purposes
4. The heat is generated in small amounts and does not harm the cells or the organelles	The heat generated is enormous and is often accompanied by emission of light

Some Useful Terms

Adenosine Diphosphate (ADP) A compound with two phosphate bonds, the second bond being energy-rich, forms ATP by the addition of inorganic phosphate.

Adenosine Triphosphate (ATP) A compound containing three phosphate groups carrying two high energy bonds; the source of high energy phosphate for energy requiring reactions in the cells

Aerobic Cellular respiration carried out with the help of oxygen

Alveoli (sing Alveolus) Small air sacs of the lung through the walls of which gaseous exchange takes place between blood and air

Anaerobic Cellular respiration carried out in the absence of oxygen

Anaerobe An organism which performs cellular respiration in the absence of oxygen

Coenzyme An organic nonprotein molecule essential for the activity of some enzymes, several coenzymes are derived from vitamins

Cytochromes A group of coloured iron-containing compounds which form a part of the electron transport chain in the cellular oxidation processes

Diaphragm A sheet of muscular tissue separating thorax from

abdomen, aids in breathing

Electron Transport Movement of electrons from substrates to oxygen catalyzed by the respiratory chain during respiration

Fermentation The energy-yielding enzymatic breakdown of organic substances that takes place in certain microorganisms under anaerobic conditions usually accompanied by evolution of heat and CO_2 and formation of alcohol, lactic acid, etc

Gill Arch The incomplete jointed skeletal ring supporting a single pair of gill slits in fishes

Gill Lamellae Thin plate-like structures in the gills through which gaseous exchange takes place

Glycolysis Anaerobic process of breaking down of gluose into pyruvic acid that occurs in the cytoplasm

Medulla Oblongata The hindermost division of the brain which merges with the spinal cord

Operculum A lid, gill-cover of fishes

Oxidative Phosphorylation Coupling of phosphate with ADP to form ATP linked to electron transport chain

Things to Do

1 Place a cockroach or an earthworm inside a conical flask Suspend a small tube containing sodium hydroxide inside it Connect this flask to a beaker containing water, through a U-shaped capillary tube What do you find

(a) after one hour?

(b) if the animal is replaced by germinating pea or gram seeds?

(c) if the experiment is carried out with the flask in a water bath at a higher temperature?

2 Place half a dozen earthworms inside a thermos flask or damp cotton wool Fix a sensitive thermometer through the cork closing the mouth of the thermos Read the temperature for the next few hours Repeat the experiment using germinating seeds Interpret your observations

3 Go to a nearby pond located near your school or house Catch some mosquito-fish with the help of an insect-net taking care that they are not injured in any way Acclimatize them for a few hours under laboratory/local conditions in previously stored tap-water Perform the following experiments

(a) Count opercular movements per minute of the fish while at rest and following forced exercise Does the number vary in the two events? If so, why?

(b) Skilfully suture the mouth of the fish with a clip and immediately release it back into water What happens to the opercular movement?

(c) Apply a thin layer of vaseline on the surface of gills of the fish on both the sides Comment on its behaviour

4 Remove a gill from a freshly killed or live fish Examine its parts under low power of a microscope, or hand lens Record observations on the structure of gill filaments

5 Examine the caudal fin of a live mosquito-fish under the low power of a microscope Notice capillary circulation Do all red blood corpuscles move in the same direction? If not, why?

Test Yourself

1 Mark true (T) or false (F)

(a) Two molecules of ATP are synthesized during glycolysis. - T

(b) Glycolysis does not occur during anaerobic respiration. - F

(c) The cellular respiration process is different in plants and in animals F

(d) Anaerobic respiration of yeast leads to the evolution of carbon dioxide. F

(e) ATP contains energy-rich bonds

(f) Adult toad breathes through gills

(g) Alveoli are found in fishes - F

2 Tick (✓) the correct answers.

(a) The Krebs cycle occurs in
   (i) grana
   (ii) mitochondria
   (iii) lysosomes
   (iv) cytoplasm

(b) Oxidative phosphorylation results in the synthesis of
   (i) ADP during aerobic respiration
   (ii) NADP during anaerobic respiration
   (iii) cytochromes
   (iv) ATP during aerobic respiration

3 Name four different organs of respiration, and mention the animals in which they are found

4 Fill in the blanks

(a) In higher plants gaseous exchange takes place through________

(b) The source of oxygen for aquatic animals is ________

(c) Cytochromes form a part of the________ ________ ________

(d) The ultimate acceptor for hydrogen in respiration is ________

5 Match Column I to Column II.

Column I	*Column II*
(a) Krebs cycle	(i) pyruvic acid
(b) glycolysis	(ii) oxidation reduction
(c) oxidative phosphorylation	(iii) citric acid
(d) electron transport chain	(iv) lactic acid
(e) anaerobic respiration	(v) amino acid
	(vi) ATP

6 Distinguish between

(a) oxidative phosphorylation and photophosphorylation

(b) aerobic respiration and fermentation

7 Why do aquatic animals die if there is an oil spill on the ocean?

8 Can a living organism survive without performing glycolysis? Give reasons for your answer.

Try to Answer

1 Mention the respiratory structures and their role in a flowering plant

2 Are the pulses that are sold in grocery shops alive? Devise an experiment to support your answer

3 Frog and tortoise are amphibious. How do they respire in water?

4 Point out three important differences between aquatic and terrestrial respiration.

5 What is common in the structure of gills and lungs that make the exchange of gases possible?

6 Which of the following animals can breathe as well as respire? Give reasons·

   (i) salamandar
   (ii) earthworm

(iii) cockroach

(iv) starfish

(v) dogfish

(vi) lizard

(vii) squirrel

(viii) sponge

(ix) *Paramoecium*

(x) water snake

7 Point out the differences, if any, in the initial breakdown of glucose under aerobic and anaerobic conditions

8 Is there any link between respiration and functioning of a brewery? Discuss

9 Can we call the complete combustion of coal in a railway engine producing carbon dioxide and energy as a process of respiration? Argue

10 What will happen if

(a) dilute molasses is inoculated with yeast cells?

(b) there is an excessive accumulation of lactic acid in muscle during the course of heavy exercise?

(c) grease is applied over the upper and lower surfaces of leaves of a flowering plant?

(d) glucose is put to complete oxidation in the body of an organism?

16

Water Relations

Importance of water, Diffusion, Differentially permeable membrane, Endosmosis, Exosmosis, Turgor pressure, Osmoregulation, Plasmolysis

YOU MUST HAVE weighed yourself on a weighing machine on several occasions Did you ever realize that of all the constituents making up your body weight, about 65 per cent is water? In fact, 65 per cent of your blood, 75 per cent of muscles, 60 per cent of red blood cells and 90 per cent of blood plasma consist of water Like yours, 50-95 per cent of the body weight of all living organisms, whether plants or animals, is in the form of water. It is by far the most abundant cellular component If any living being is deprived of this important fluid, you would notice that hardly any function of life can be carried out Its inadequate supply or discontinuation can cause even death

The indispensability of water is due to its unique physical and chemical properties It is an almost universal solvent, a quality which enables it to facilitate several chemical reactions. It is also an important medium in which nutrients are absorbed, carried into the cells, transported from cell to cell, and eventually passed out as waste products. Its abundance, liquid state, high specific heat and heat of vapourization, low density, and cohesion and adhesion properties furnish it with untold capabilities of performing innumerable physiological and biochemical activities.

With a view to appreciate and understand the intricate relationship between water and the animate objects, it is necessary for us to acquaint ourselves with some of the basic phenomena and principles involved in it

Diffusion

If you open a bottle of perfume in a room, its scent would soon spread into the entire house, even if the air around is motionless How does this happen? This must have resulted from the migration of vapours from one place to another Similarly, if you place a few crystals of potassium permanganate at the bottom of a beaker full of water, you would initially see dark red colour developing around the crystals, which is less intense at a distance away from it Finally, however, the entire solution turns uniformly pink This is because the dissolved crystal particles, by their kinetic energy, have become evenly distributed among the water molecules (Fig 16-1A-D)

We can now generalize these two phenomena by saying that there has been a net movement of particles of a particular substance (gas, solid, liquid) from a region of higher concentration to that of lower concentration Such a molecular traffic is called diffusion The diffusing molecules

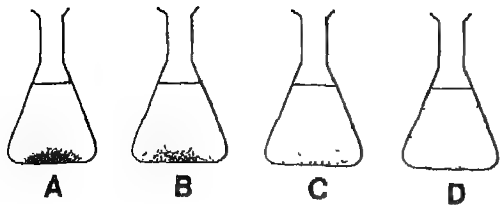


Fig 16-1 A-D Stages in the dissolution of crystals of potassium permanganate

and ions exert a pressure as a result of their ceaseless activity, and continue to move from areas of higher to lower diffusion pressure until an equilibrium is reached The rate of diffusion increases with the rise in temperature It is the fastest in gases, less rapid in liquids and the slowest in solids

Diffusion plays an important role in living cells It helps to equalize the distribution of metabolites evenly, and facilitates transport of materials such as carbon dioxide, oxygen, water and salts. For example, it brings about the entry and exit of oxygen through stomata in both directions In plants it helps in assimilation of carbon dioxide, and movement of sugar, solutes and water between adjacent cells In animals it assists in the transference of soluble food materials to different parts of the body through blood

Whenever any substance diffuses into or out of a living cell, it must pass through the cell wall and/or the plasma membrane or the tonoplast. The exact nature of this membrane depends on the arrangement of phospholipids and protein molecules constituting it Accordingly, it may restrict, permit discriminatively, or prevent the passage of dissolved substances, so that some particles can pass freely, others slowly, and still others hardly Hence such membranes are rightly disignated as selectively permeable membranes The degree of their permeability plays a significant role in the maintenance of life activities.

Osmosis

It is commonly defined as a special type of diffusion of liquid through a differentially permeable membrane. Living membranes, such as the plasma membrane, act as a selective barrier since all substances can neither pass through it nor at the same rate, if they can In other words, osmosis involves mobilization of substances in solution from higher to lower concentration through a selectively permeable membrane, with each substance continuing to move independently of the other until an equal concentration is attained on either side of the membrane

Osmosis can be demonstrated easily by an improvised osmometer For this, take a small thistle funnel and tie its mouth with a natural membrane taken from either the skin of the leg of a frog or from the bladder of a pig Fill it with 5 per cent sugar solution coloured with a drop of safranin, and invert it in a beaker containing water (Fig 16-2) Mark the level of the sugar solution on the stem of the funnel After an hour or so, you will observe a rise in the level as a result of an increase in the volume of water inside the thistle funnel This movement of water molecules, through a membrane towards an area of greater

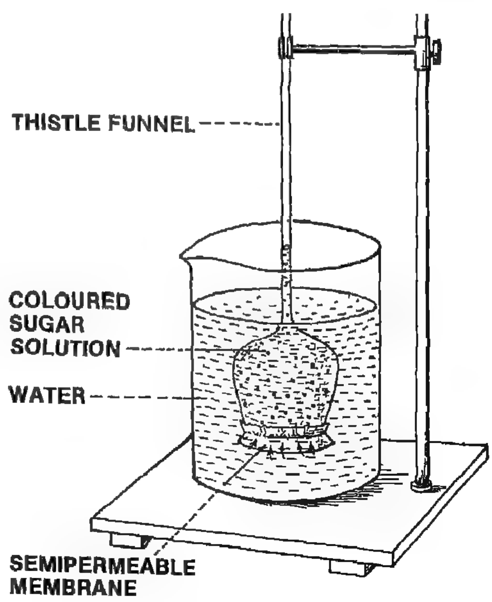


Fig 16-2 Improvised osmometer

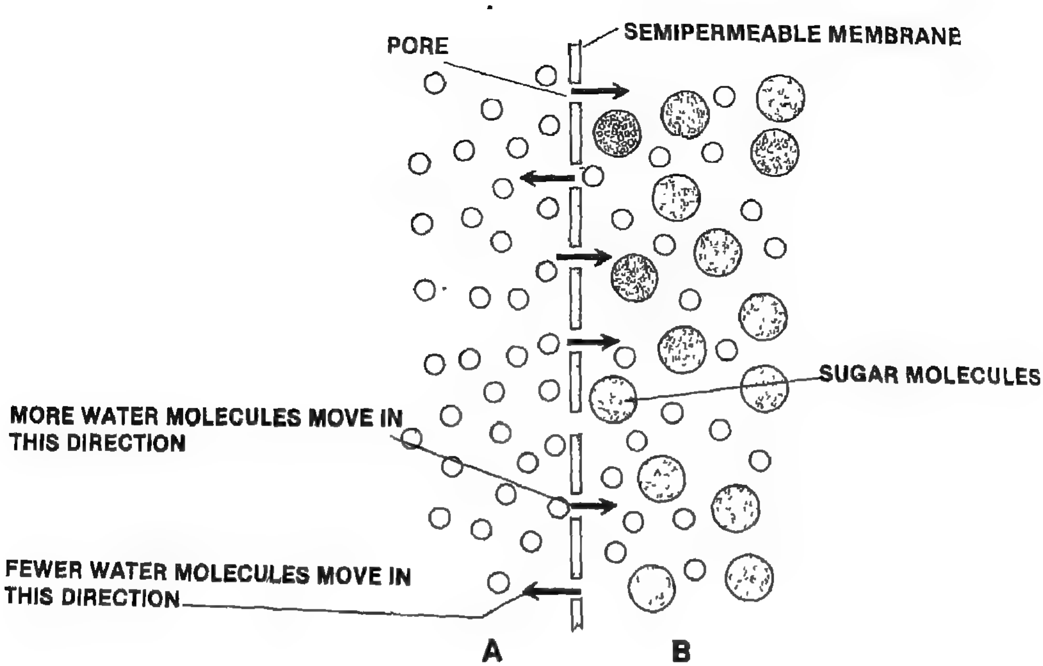


Fig. 16-3 Phenomenon of osmosis, high (A) and low (B) concentrations of water molecules are separated by a semipermeable membrane

concentration of a dissolved substance, is known as endosmosis The entry of water and minerals through the cytoplasmic membranes of the root hairs in plants is a good example

The force exerted by the outside to inside flow of water molecules is called osmotic pressure, and this is directly proportional to the difference in concentration of water molecules on either side of the membrane (Fig 16-3) Osmotic pressure does not exist when the concentration of dissolved particles on both sides of the selectively permeable membrane is equal Such a solution is said to be isotonic. If the outside solution has higher concentration of water (lesser concentration of solute), it is termed hypotonic and results in the development of osmotic pressure which brings about the flow of water from outside to inside. In a reverse situation, when the outer medium has higher concentration of solute (lower of water), the solution is called hypertonic and results in exosmosis or the movement of water from inside to outside

Although green algae inhabiting fresh water are surrounded by a hypotonic medium, their cells become turgid but do not continue to swell and burst because of the development of an internal pressure This pressure exerted on the liquid by the rigid walls and membranes of a turgid cell is called turgor pressure. When this relationship between the internal and external forces is not equal and opposite, or loses its equilibrium, it would culminate in partial or total collapse of the living body

Osmoregulation

The osmotic relationship between a cell and its surrounding medium is of paramount significance in the life of an organism—whether a plant or an animal. For example, a marine fish lives in an environment of relatively low water (high salt) concentration Unless it possesses a

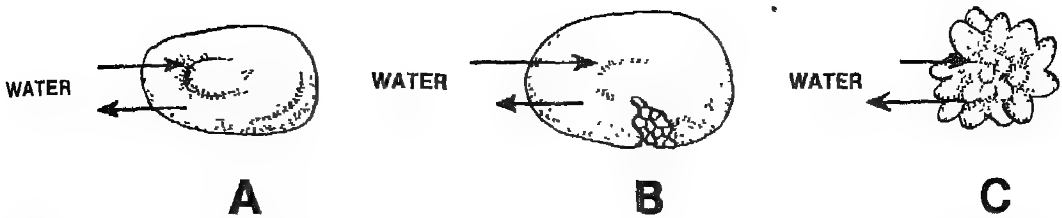


Fig 16-4 Behaviour of red blood cell in isotonic (A), hypotonic (B), and hypertonic (C) solution, respectively. It is normal in A, swollen to the point of bursting in B, and shrunk in C

mechanism to regulate the osmotic concentration of its body fluid, water would move out of its blood stream into the ocean and it would soon become too dried to keep alive. A close examination of the system of water and salt adjustments of such a fish reveals that it drinks large quantities of water to overcome dehydration, but this produces another problem—it also takes in too much of salt along with water. If this extra salt is not expelled from the body, its life processes would quickly disorganize, and, therefore, the gill membranes help it to actively excrete salts.

Fresh water fish, on the other hand, has a different mode of osmoregulation. Its blood and tissue fluids are more concentrated than the water around, which thus moves into the blood resulting in the dilution of salts and other blood substances. The fish, therefore, drinks less water, and its concentration is also adjusted through the kidneys by excreting large amounts of diluted urine. This creates the problem of loss of essential salts along with water which are replenished into the blood through specialized cells on the gills.

Plasmolysis

When a living cell is immersed in a solution which is more concentrated than the cell sap (hypertonic), several changes occur in its appearance.

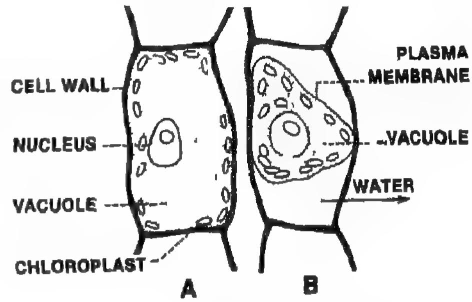


Fig 16-5 Normal (A) and plasmolyzed (B) cells

The plasmalemma is pulled away from the cell wall, the tonoplast too shrinks, and there is a general loss in the turgidity of the cell (Fig 16-5). Such a cell is considered to be plasmolyzed, and the phenomenon known as plasmolysis. These cells can be deplasmolyzed if they are placed in a hypotonic solution. A slow movement of water through the cytoplasmic and vacuolar membranes will again turn the flaccid cell turgid. This process can be reversed only if the severity of plasmolysis has not permanently damaged the cell. When the signs of plasmolysis begin to appear in a turgid cell (incipient plasmolysis), it is an indication that the osmotic potential of the outside medium is approximately the same as that of the cell sap.

Some Useful Terms

Adhesion The molecular force of attraction in the area of contact between unlike bodies that acts to hold them together

Cohesion The molecular attraction between particles within a substance that acts to unite them

Diffusion The movement of molecules or ions resulting from their kinetic energy that tends to disperse them throughout the medium

Hypertonic A solution having a higher concentration of solute molecules and a lower concentration of solvent molecules (water) than that of a solution to which it is compared

Hypotonic A solution having a lower concentration of solute molecules and a higher concentration of solvent molecules (water) than that of a solution to which it is compared

Isotonic A solution having the concentrations of solute and solvent (water) molecules exactly equal to those in another solution to which it is compared

Osmotic Pressure The force that a dissolved substance exerts (by virtue of the motion of its molecules) on a semipermeable membrane through which it cannot pass

Osmoregulation The process by which a cell or an animal controls the amount of water in its body, and the concentration of various solutes and ions in the body fluid

Phospholipid A group of fatty compounds composed of phosphoric esters, such as lecithin

Plasmolysis The shrinkage of protoplasm in a cell due to removal of water by exosmosis

Specific Heat The amount of heat required to raise the temperature of one gram of a substance through 1° C

Things to Do

1 Take a glass tube with open ends, of the diameter of a test tube Fix a cork with a pad of cotton moistened with ammonium hydroxide on one end, and another dipped in hydrochloric acid on the other What does the presence of white smoke in the tube demonstrate?

2 Take a large potato tuber or a turnip, peel off the skin, and cut a 5 cm cube Scoop out a 3 cm deep cavity in the middle with the help of a cork-borer of narrow diameter Wash it thoroughly and place it in a dish containing water. Add a small quantity of strong sugar or salt solution coloured with safranin and mark the level of the solution by carefully inserting a pin inside the hollow Observe the level in the cavity every day. Rise in the level would demonstrate the phenomenon of endosmosis. Repeat the experiment using a boiled potato or turnip and compare your observations

3 Pull out a strip of epidermis from the leaf of *Rhoeo* or *Tradescantia* and mount it in a drop of water Examine under microscope and make a sketch showing the cell constituents. Remove the water by touching the edges of the cover glass with a piece of blotting paper and put a few drops of concentrated sugar or salt solution on the other edge Make another diagram and match it with the previous drawing Replace this solution again with the tap-water What do you observe?

Test Yourself

1 Write short notes on.
   (a) diffusion
   (b) osmoregulation
   (c) plasmolysis

2 Define the terms
   (a) selectively permeable membrane
   (b) osmosis
   (c) hypotonic solution
   (d) turgor pressure
   (e) incipient plasmolysis

3 Mark true (T) or false (F).
   (a) No osmosis takes place when the cell is placed in hypertonic solution
   (b) Exosmosis takes place during plasmolysis
   (c) The plasma membrane allows the passage of all substances
   (d) During osmosis water moves from a concentrated sugar solution to a dilute sugar solution
   (e) Marine fishes maintain balance with the surrounding water by excreting salt from gills.
4 Distinguish between
   (a) turgor pressure and osmotic pressure
   (b) isotonic and hypertonic solutions
5 Fill in the blanks:
   (a) Water and minerals enter the plant body by the process of_______.
   (b) If a plasmolyzed cell is placed in water it becomes_______
   (c) The pressure exerted by the cell wall and membrane is called_______
   (d) The movement of particles from an area of higher concentration to that of lower concentration is called_______
   (e) The plasma membrane is _______ permeable

Try to Answer

1 Why do raisins swell in your sweet 'kheer' (rice pudding)?
2 The leaves of wilted lettuce, if kept in cold water, become crisp, how?
3 The efficiency of cells is dependent upon their small size Comment
4 Distinguish between filtration and diffusion.
5 What would be the result if the human blood cells were twice their present size? Would they absorb oxygen more efficiently?
6 The grass in your lawn becomes greener if you add a little fertilizer to it, but it dies if you add more Why?
7 Fatty molecules can enter the plasma membrane more readily than other molecules of similar size Why?
8 When your foot is sprained and becomes swollen, your mother advises you to soak it in hot water containing lots of common salt Is this counsel based on any scientific principle?
9 What would happen if you swim in sea water for a long time?
10 How does the shore crab, a marine invertebrate, manage to live both in sea and brackish waters?

17

Transport

Active absorption, Passive absorption, Conduction, Ascent of sap, Transpiration, Guttation; Heart, Arteries, Veins, Circulation—Pulmonary, Systemic, Blood, Lymph

IN single-celled organisms the entire cell is in direct contact with the external environment, and any exchange between the two can easily take place by simple diffusion. In more complex multicellular organisms only a small number of cells on the surface are exposed to the environment They have special sites for ingestion, egestion, exchange of gases, and so on. There is need for contact between these sites and the cells lying within the body. For example, food processed by the digestive system, and oxygen taken in during respiration must be delivered to all the cells. A fluid exchange medium is, therefore, essential for a multicellular organism While water is the medium of transport in plants, blood performs this function in most of the animals In this chapter, we propose to discuss the involvement and role of various tissues and organs in the vital transportation activity.

Plants

Plants obtain inorganic nutrients in the form of liquid or gas They should, therefore, have an efficient system for the absorption of water and exchange of gases. In most species, large quantity of water is absorbed by the plant, but a considerable proportion of it is lost into the atmosphere through its aerial parts either in the form of water vapour (transpiration) or as liquid water (guttation) This continuous flow helps in the distribution of not only water but also nutrient materials (translocation) to different areas of the plant body

ABSORPTION

Although in land plants, water enters mostly through roots, it can also be absorbed through other parts such as leaves, stems and reproductive organs. Root hairs particularly provide a large absorbing area since they are in intimate contact with the soil particles having a thin film of water and dissolved mineral substances around them.

Entry of water takes place mainly through a combination of diffusion, osmosis and its active uptake The internal distribution is achieved mainly by diffusion and streaming of the protoplasm (cyclosis) The transfer of water and dissolved salts can occur only if there is a potential gradient between the soil particles and the cells, as well as between the cells themselves This passive absorption does not need any metabolic energy On the other hand, the movement of molecules from regions of lower to higher concentration, being an uphill task, requires expen-

diture of energy (ATP) by the cells and hence is designated as active absorption

Root tips also constitute an effective absorbing region for water and minerals which after absorption by the epidermal cells, traverse through cortex, passage cells of the endodermis and pericycle, penetrate into the primary xylem and eventually move upward through the continuous tube-like cells of the xylem (Fig 17-1), without traversing the phloem

The elongated, lignified, dead tracheids of the xylem with a large number of vessel elements placed end to end, without any cross walls, form long duct-like structures which are very congenial for an uninterrupted continuous passage of water in the vertical direction The perforated side walls of the tracheids, vessels and ray parenchyma help in the lateral movement of water Some water can pass through even the xylem fibres closely associated with them.

The rate of absorption is, however, dependent on several factors such as the characteristics and moisture content of the soil, solute concentration in the soil, extent of the root system, rate of growth of roots, concentration of the cell sap, and the structural peculiarities of the tissues through which the water molecules have to pass.

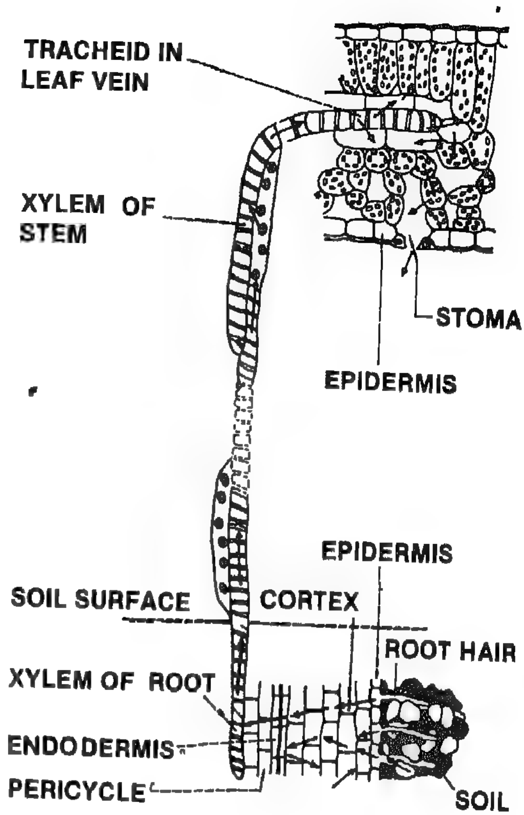


Fig. 17-1 Diagram showing entry of water from soil into root hair (absorption), its path of movement through stem to leaf cells (conduction), and its escape as water vapour to atmosphere, mainly through stomata (transpiration)

CONDUCTION

Although long distance transport of water and nutrients in a plant (translocation or conduction) occurs through the tracheids and vessels of the xylem and through the sieve tube elements of the phloem, respectively, the forces responsible for their rapid and efficient transportation need further elaboration

The lifting up of water and minerals from root tip to leaf tip (also known as ascent of sap) occasionally to a height of 90 to 100 metres, requires quite strong push and pull forces against gravity These are simultaneously provided by osmosis, capillary action, root pressure (hydrostatic pressure created by absorption of water by root cells), and the pull exerted as a result of transpiration

Air pressure creates a force of only one atmosphere which can lift water to about 10 metres, but this is quite inadequate for raising water in very tall trees The capillary action in the thin, narrow xylem elements, which is sometimes cited as a method responsible for the rise of water in plants, does not explain satisfactorily this flow of water. Most plant physiologists believe that root pressure is also responsible for translocation of water, but this too, is too slow to account for the volume of water pushed up through the xylem.

Moreover, most tall conifers do not show root pressure of high magnitude You are perhaps aware that water column in enclosed tubes have a high degree of cohesion and a pull or tension of 30 atmospheres or more is required to break this column. Since xylem tracheids and vessels have a great semblance with these tubes, this idea has also been put forth as the shoot tension theory to explain water translocation However, it appears that along with the above-mentioned forces, transpiration pull is the major factor which creates a water deficit in cells and determines the rate of movement of water

TRANSPIRATION

While the plant absorbs large amount of water from the soil, it retains a very small portion of it for its vital activities and the greater part of it is lost from its surface into the atmosphere A maize plant loses as much as 3-4 litres of water per day and a field of corn would loose about 85,000 litres of water per acre during the growing season[1] This loss of water vapour from a living plant is known as transpiration

Water may be transpired directly through the cuticle, a waxy layer covering the leaf surfaces, by diffusion of water vapour (cuticular transpiration), or through a large number of microscopic openings called stomata (stomatal transpiration, Fig. 17-1) Sunken stomata reduce water loss Water is also lost through lenticels, small openings in the corky tissue covering stems and twigs (lenticular transpiration)

Since most of the water loss occurs through stomata, their structure, frequency, distribution, and opening and closing greatly influence the rate of transpiration Several other factors such as relative humidity of the atmosphere, velocity of wind, light intensity, temperature and soil conditions also affect transpiration Besides these environmental factors, the structural features (known as internal factors), habit and habitat of the plants also influence the rate of transpiration

Decrease in leaf surface, rolling of leaves during drought, absence of leaves, and presence of epidermal hairs and sunken stomata decrease, restrict or prevent transpiration

Transpiration is considered to be a necessary evil It helps in the flow of water, provides a system of transport of minerals from the soil, cools the plant, and maintains proper temperatures for other physiological activities In fact, it is essential for the general water management of the plant

Many times, water loss from the plants occurs in the form of liquid, rather than as water vapour. You might have also seen some droplets

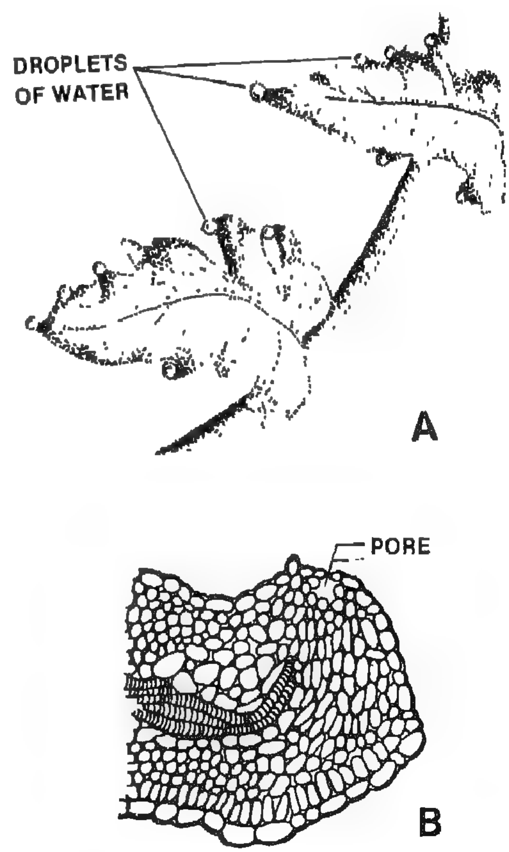


Fig 17-2 A Guttation droplets along margins of tomato leaves B Hydathode as seen in sectional view

of moisture shining along the margins of leaves in some plants (Fig 17-2A), especially when they are growing in moist, warm soil in humid environment. This kind of water loss is termed as guttation and occurs through specialized openings called hydathodes which are situated at the tips of the veins of leaves (Fig 17-2B) When water uptake exceeds water loss through transpiration, a hydrostatic pressure is built up in the xylem ducts which is literally responsible for pushing out water through the hydathodes The guttation liquid generally contains a large number of dissolved substances such as nitrates, nitrites, calcium, potassium, magnesium, sodium, zinc, copper, aluminium, and its composition varies from plant to plant

Animals

In animals, the vital transportation activity is carried out by the circulatory system This system, in order to perform its various functions, must possess exchange sites of two kinds It should be able to communicate with the external environment to pick up useful substances and throw out waste products It should also be able to contact all the cells of the body to take out waste products from them, and supply useful substances In fact, there are several exchange sites of each kind

In unicellular organisms such as *Amoeba* and *Paramoecium*, there is no need for a specialized circulatory system Useful substances such as oxygen and water enter the cell by simple diffusion and active transport. Cytoplasmic streaming (Fig 17-3) takes care that every portion of the body is adequately supplied with materials. The food vacuoles also move with the aid of such protoplasmic movements As digestion is completed, the digested food molecules pass from the vacuoles into the cytoplasm by diffusion Waste products diffuse out through the cell membrane

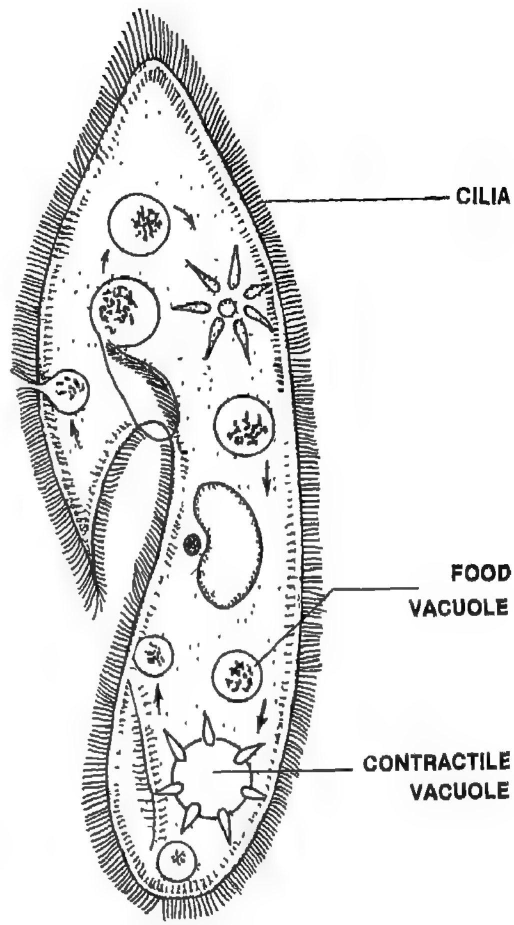


Fig 17-3 Cytoplasmic streaming in *Paramoecium* (shown by arrows)

In simple multicellular organisms such as sponges and coelenterates, water circulating through certain channels in the body acts as a medium of transport in them (Fig 17-4) In the more complex planarians too, there is no true circulatory system Instead there is a small amount of fluid bathing the internal organs whose circulation results from contraction and expansion movements of the body.

The annelids are far more complex in organization. The earthworm, for example, has a well-developed circulatory system It consists of a network of blood vessels which is in contact with almost all cells of the body Blood is the fluid flowing through this closed system of tubes, being confined to it all the time. In order to main-

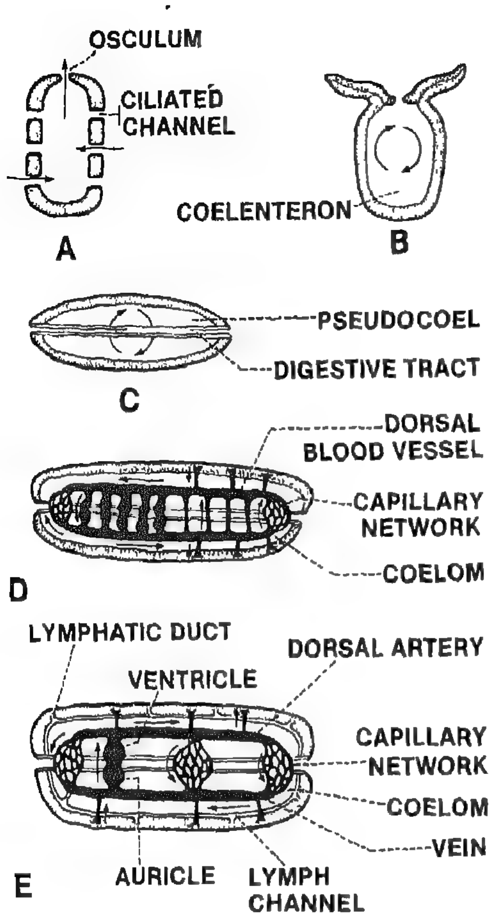


Fig 17-4 Internal transport system in sponge (A), coelenterate (B); planarian (C), earthworm (D), and vertebrate (E)

tain its flow, a pump is necessary The essential components of its circulatory systems are. (a) blood—the fluid aiding transport; (b) blood vessels—a system of conducting channels, (c) a pump—a function performed by the pulsatile hearts and the dorsal blood vessel; and (d) specialized exchange sites where the blood vessels break up into a network of small vessels, the capillaries. The blood plasma of earthworms consists of mainly water with dissolved substances and a pigment called haemoglobin, which helps in the transport of oxygen and nutrients

The insects such as cockroach, have an open system of blood circulation. The blood has no respiratory pigment and is more or less colourless It passes through a closed vessel, the aorta, only for a part of its circulation. For the rest, it flows through the body cavity, the haemocoel and tissue spaces The pumping function is provided by a many-chambered heart The blood does not transport oxygen and carbon dioxide For these respiratory functions, there is a separate tubular system called the tracheal system.

Circulation in all vertebrates is carried out by a well-developed closed circulatory system. A single heart is made up of muscles whose contractions give the necessary pressure for blood flow Thus, heart is the central pumping organ in the circulatory system Blood leaves the heart by means of blood vessels called arteries and is returned to the heart by veins. To form an exchange site, a branch of an artery (arteriole) breaks up into a web of thin-walled blood vessels, capillaries, which reunite to form a branch of a vein (venule).

Let us take the example of the circulatory system of a mammal Its heart functionally consists of two independent yet synchronized pumps —the right side and the left side (Fig. 17-5). While the former is responsible for pumping blood to the lungs (pulmonary circulation), the latter pumps blood to the rest of the body (systemic circulation) In a median vertical section, of the heart (Fig 17-5), one can easily distinguish between the left and right auricles and the left and right ventricles. These form the four chambers of the heart. The muscle contraction pattern is such that the auricles contract in unison, followed almost immediately by the two ventricles After some gap the auricles contract again. One heart beat is thus constituted by an auricular contraction followed by a ventricular contraction

Let us now follow the pattern of blood flow in a mammal (Fig 17-6). When the auricles contract, blood is emptied into the respective ventricles.

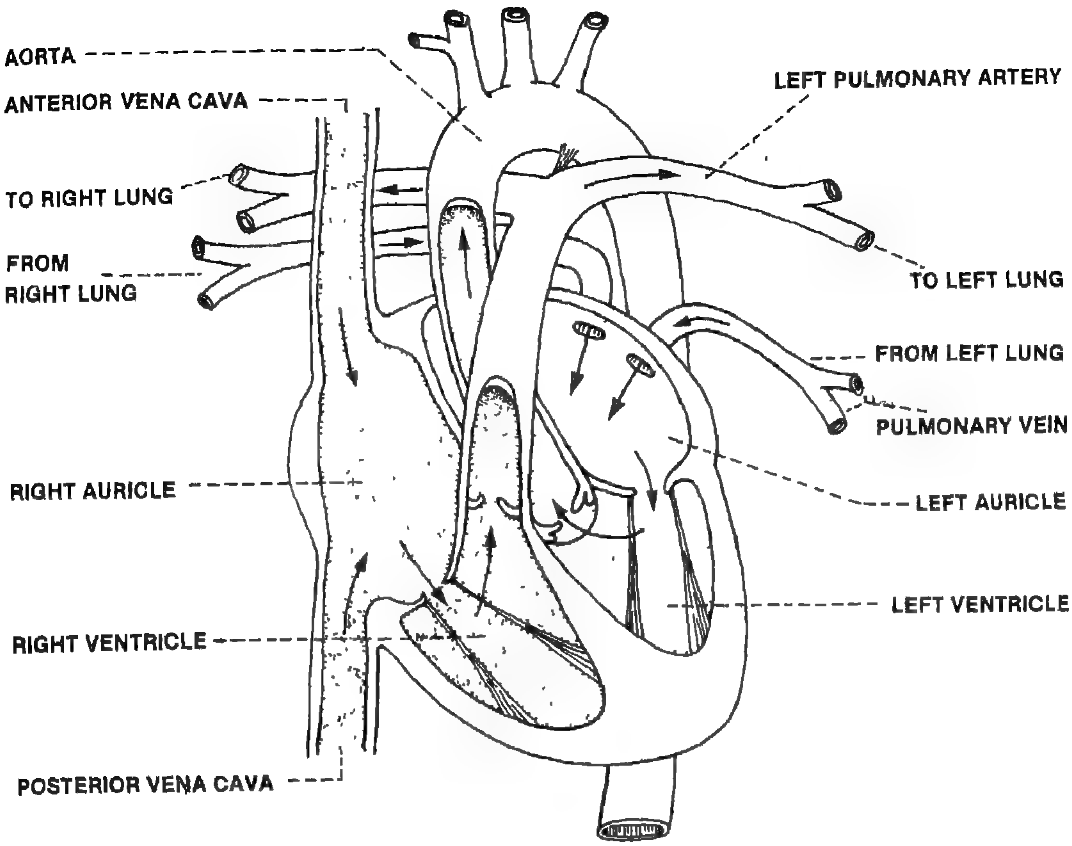


Fig 17-5 Median vertical section of human heart, arrows indicate direction of blood circulation

Remember, there is no direct contact between the two halves of the heart When the ventricles contract, blood from the right ventricle moves into the lungs from where it is brought back to the left auricle This we termed as pulmonary circulation. At the same time, blood from the left ventricle is pumped into a major artery called the aorta which gives off branches to almost all the parts of the body. As blood passes through the intestinal wall, it picks up absorbed food. Through the kidneys it is filtered and cleansed of the excretory products. While passing through the tissues, it supplies the cells with oxygen, and picks up carbon dioxide and waste products Several veins from different organs collect blood and unite and reunite to form two large veins—the superior vena cava, bringing back all the blood from the head region and the inferior vena cava, returning blood from the rest of the body The two venae cavae empty their contents into the right auricle. This is the systemic circulation

In man the heart beats about 72 times a minute maintaining a constant flow of blood in the circulatory system. The total volume of blood in the system is about 5 litres. Approximately 5 litres of blood is pumped out by the heart every minute

BLOOD

As we have studied above, blood is the fluid flow-

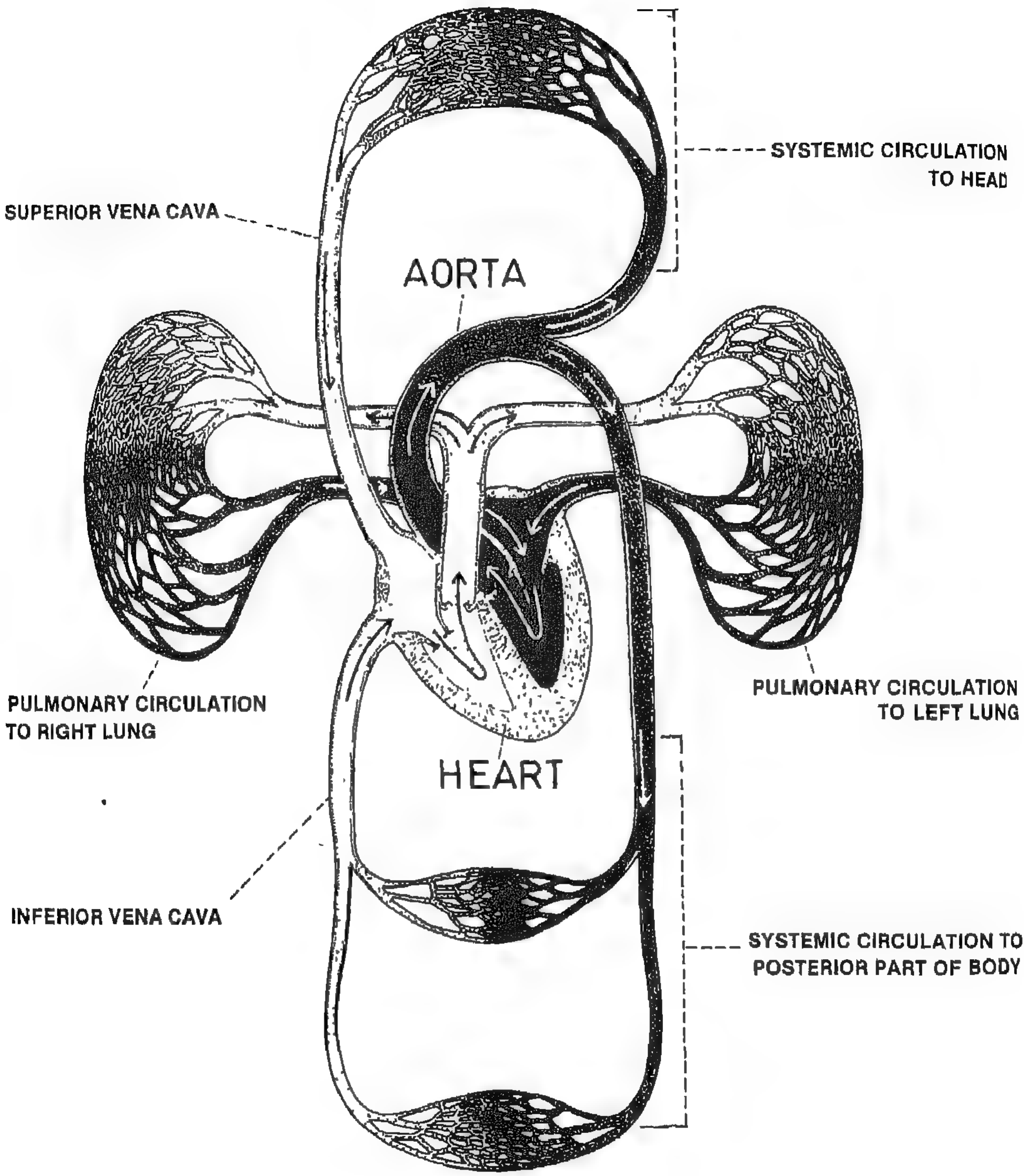


Fig 17-6 Circulatory system of a mammal, direction of blood flow is indicated by arrows

ing through the circulatory system It performs the following functions,

(a) **in respiration** transport of oxygen from lungs to the tissues and of carbon dioxide from the tissues to the lungs,

(b) **in nutrition** transport of absorbed food substances to the cells,

(c) **in excretion** transport of metabolic wastes

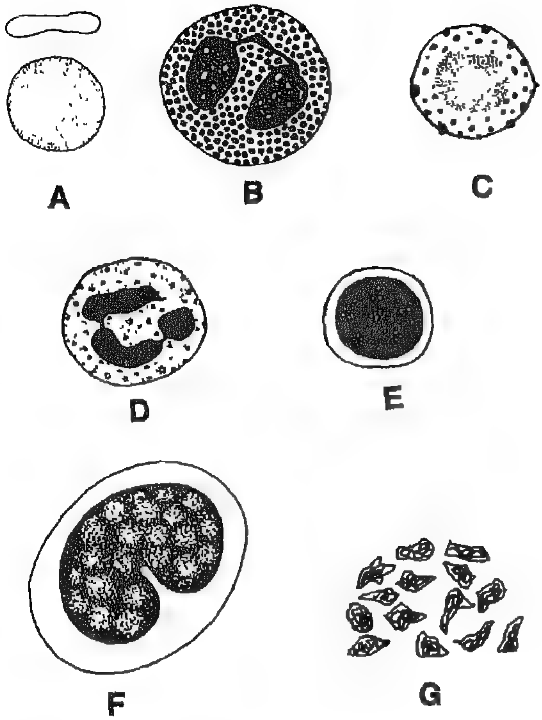


Fig 17-7. Blood cells of a mammal: red blood cells (A), white blood cells (B-F), blood platelets (G)

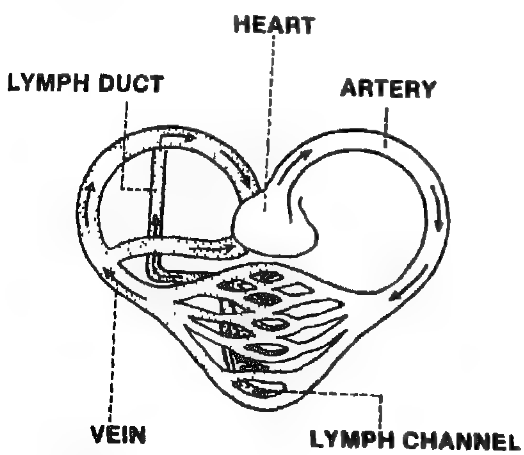


Fig 17-8 Lymphatic system (closely stippled) of a mammal showing its relationship with venous system (sparsely stippled) and arterial system (unstippled)

to the kidneys, skin and intestine for their removal;

(d) **in regulation of metabolism** transport of hormones from their site of production to that of their action,

(e) **in other regulatory mechanisms** maintenance of body temperature, osmo-regulation, and acid base balance

Composition Blood is a specialized connective tissue It is present in many invertebrates and all vertebrates Its functions too are the same but its composition varies For example, the blood of mammals consists of cells floating in a watery medium, the plasma The blood cells are of three kinds—red blood cells, white blood cells and platelets (Fig. 17-7). In man, the red blood cells or erythrocytes, number about 5 million per cu mm of blood Each erythrocyte is a round disc, thinnest at the centre, giving it a biconcave side view These cells are devoid of nuclei. Their main constituent is a pigment called haemoglobin which transports oxygen The white blood cells or leucocytes are larger, fewer in number and contain one nucleus each They are of five different types Their major function is to provide immunity to the body. Blood platelets or thrombocytes, are small spherical bodies, numbering about 300,000 per cu mm of blood. They have an important role in the formation of a solid plug called clot at the site of injury to a blood vessel, so as to prevent further loss of blood

LYMPH

We have described the circulatory system as a closed channel system However, this is not strictly true. At the tissue level, leakage of leucocytes and plasma containing respiratory gases, nutrients and hormones takes place from the blood capillaries The tissue cells, therefore, get bathed with this fluid. If the volume of blood has to be maintained, this fluid must be returned to the blood stream This is brought about through the lymphatic system (Fig 17-8) which runs

parallel to the veins It collects the fluid, termed lymph, in the lymph channels which unite to form the lymph ducts These then open into a pair of veins near the neck, termed as subclavian veins Lymph thus aids the blood in its functions.

Some Useful Terms

Active Transport The movement of substances across membranes, irrespective of concentration gradient, requires chemical energy

Arteriole A small branch of an artery

Capillary The finest tubular branches of circulatory system connecting arteriole and venule

Cyclosis The circulatory movement of protoplasm within certain kinds of cells

Guttation The exudation of water in liquid form by plants usually through special structures (hydathodes) present on the tips of veins

Hydathode A pore usually at the end of a leaf vein from which water is exuded

Lenticel A small lens-shaped opening in the periderm of stems and roots packed with loose corky cells, permits gaseous exchange between the plant and atmosphere

Inferior Vena Cava The main vein in the vertebrates conveying blood from the posterior parts of the body to the heart

Leucocyte A white blood corpuscle (WBC) of the vertebrates or colourless cell of blood of many other animals

Pulmonary Circulation The flow of blood from the heart to the lungs and back

Superior Vena Cava The main vein which conveys blood from the head and other anterior regions of the body to the right auricle of the heart

Systemic Circulation The circuit relating to the flow of blood from the heart to various parts of the body (excluding lungs) and back to the heart

Thrombocyte A minute greyish, circular or oval body found in the blood of vertebrates; plays an important role in blood coagulation, also called blood platelet

Tracheal System A combination of air tubes and their branches which help in respiration in insects and some other arthropods

Transpiration Loss of water vapour from the plants mainly through stomata

Venule A small branch of a vein

Things to Do

1 Take a profusely watered potted herbaceous plant Detop it near a few centimetres above the soil level with a sharp razor blade What do you observe on the stump? Explain

2 Place a young balsam plant or some cut flowers with long stalks in a flask containing water coloured with red ink, preferably in the sun, or under a ceiling fan for a couple of hours Cut a free-hand section of the stem and make an outline drawing showing the distribution of the dye

3 Sprinkle common salt around the root system of a patch of grass Dig out the roots next day and compare their appearance with that of untreated plants

4 Wash your hands well, dry them with a clean towel Rub the tip of a finger with spirit-soaked cotton wool Let it dry. Prick it with a sharp needle point which has also been similarly sterilized Squeeze a small drop of blood on to a clean glass slide, add 3 or 4 drops of 0 9% sodium chloride solution, mix, and put a coverslip. Observe the shape and colour of the red blood cells visible under a students' microscope

5 Stretch the web of a frog's leg on to a glass slide holding it in position very tightly, by wrapping in a wet piece of cloth. Examine the movement of corpuscles under a students' microscope

Test Yourself

1 Fill in the blanks
   (a) The movement of protoplasm within cells is called ___________
   (b) Translocation occurs through ___________ and ___________.
   (c) Hydathodes are situated at the ends of ___________, and are responsible for ___________
   (d) The right side of the heart is responsible for ___________ circulation

2 Write short notes on any three of the following
   (a) functions of blood
   (b) systemic circulation
   (c) circulation in earthworm
   (d) absorption of water and minerals by plants

3 Define the following terms
   (a) lenticular transpiration
   (b) thrombocyte (platelets)
   (c) cyclosis
   (d) arteriole
   (e) lymph

4 Describe the adaptations of plants to lower the transpiration rate

5 Describe the various types of blood cells and their functions

6 How does a plant lose water? What are the factors that control this loss?

Try to Answer

1 List the conditions under which maximum amount of water can be absorbed and retained by the plant.

2 Enumerate the factors which control the circulation of water in a xerophyte, mesophyte and hydrophyte

3 Two gardeners transplanted some seedlings from a flower bed to flower pots. In one, the seedlings wilted, and in the other they did not What precautions must have been taken by that gardener whose method of transplantation prevented the wilting of the seedlings?

4 Which morphological peculiarities help a pine tree to decrease water loss?

5 Other conditions being constant, when do you expect the rate of transpiration to be the highest—when relative humidity of the atmosphere is 20%, 50%, 100%?

6 A red blood cell leaves the right ventricle of man. Trace its path via the circulatory system back into the right ventricle. What changes will it undergo during its trip?

7 The left ventricle wall of a human heart is thicker than that of the right ventricle Can you tell the reason?

8 How are the functions of small intestine and liver related to blood circulation?

9 What is likely to happen to a man whose blood pressure falls below normal? What will happen if it rises?

10 Anaemia is a common problem in India How do you account for this? List the symptoms shown by an anaemic person

18

Excretion

Excretion, Waste products, Secretion, Diffusion, Selective filtration, Excretory organs, Kidney and Urine formation

A LIVING organism needs energy for various activities such as locomotion and reproduction. It also requires constituent molecules for growth and repair For all these functions it depends on food The necessary energy comes from the catabolic reactions, whereas the building blocks are produced as a result of anabolism. In the process, a lot of unwanted, and even toxic by-products are formed Their elimination from the body is called excretion Along with food, water and electrolytes (e g., sodium, potassium, chloride, bicarbonate) are also taken in. To maintain a proper balance of these in the body, the excess must be disposed of The excretory system removes not only waste products but also superfluous water, and salts, so as to aid in osmoregulation. Thus, excretion can be defined as a process by which metabolic wastes are removed from the body and an osmotic balance maintained

Nature of Waste Products

The major waste product in all organisms includes carbon dioxide produced by the oxidation of fats and carbohydrates Protein metabolism results in nitrogenous wastes such as ammonia, urea and uric acid While the carbon dioxide is eliminated by the respiratory system, the nitrogenous materials are taken care of by the specialized excretory organs

Excretory Mechanisms

Excretion is carried out at different sites in various types of plants and animals by diverse mechanisms. These are secretion, simple diffusion and selective filtration

PLANTS

In simpler forms such as *Spirogyra,* the metabolic by-products simply permeate out into the surroundings In higher plants, carbon dioxide, water and oxygen diffuse out through the epidermis (as in roots) and stomata of the leaves, and lenticels of the stems and the minerals besides water through the hydathodes by guttation The surplus salts are secreted in the form of calcium oxalate crystals in pith and cortex of roots and stems (grapevine, eucalyptus) or fruits (tomato) or as calcium carbonate in the lithocysts of certain leaves (India rubber tree) Tannins, resins, mucilage and latex are some other excretory materials stored in the plants Ammonia and other nitrogenous substances are utilized for the synthesis of new compounds Some roots are also

known to excrete mineral salts, sugars, amino acids, and hydrolytic enzymes.

ANIMALS

In unicellular organisms such as *Amoeba*, carbon dioxide and nitrogenous wastes in the form of ammonia simply diffuse out into the water across the plasma membrane. A single contractile vacuole takes care of osmoregulation. In *Paramoecium*, there are two contractile vacuoles which store excess water and expel their contents across the plasma membrane from time to time In simple multicellular forms such as *Hydra* too, excretion is by simple diffusion.

In flatworms fluid and nitrogenous matter in the form of urea and uric acid are ejected by a system of branching tubes with ciliated flame cells (Fig 18-1A, B) In earthworms tubular

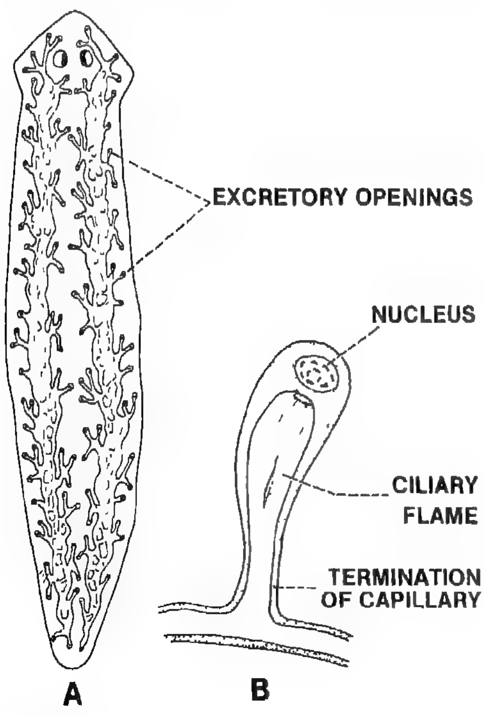


Fig 18-1 A Excretory system in flatworm
B Magnified view of a flame cell

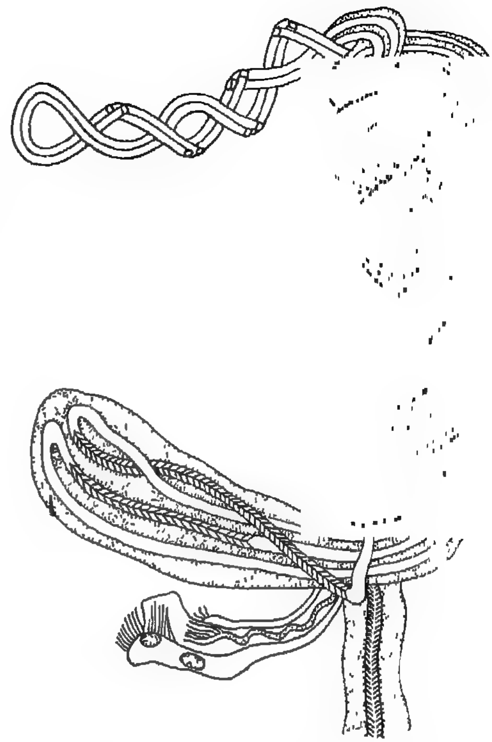


Fig 18-2 Nephridium of earthworm

structures called nephridia (Fig 18-2) collect the waste products and eliminate them either into gut or outside the body via small openings on the body wall. In insects disposal is through a bunch of long tubes called Malpighian tubules (Fig 18-3). Kidneys are the organs of excretion in vertebrates

In man, kidneys and the rest of the urinary system play the major role in excretion (Fig 18-4) A pair of kidneys lie in the abdominal cavity, one on either side of the vertebral column. Each kidney is supplied by a renal artery that brings blood along with waste products to it, and a renal vein which carries away the purified blood (Fig 18-5) The kidneys collect the products of excretion and eliminate them in the form of urine which then passes down the two tubular ureters

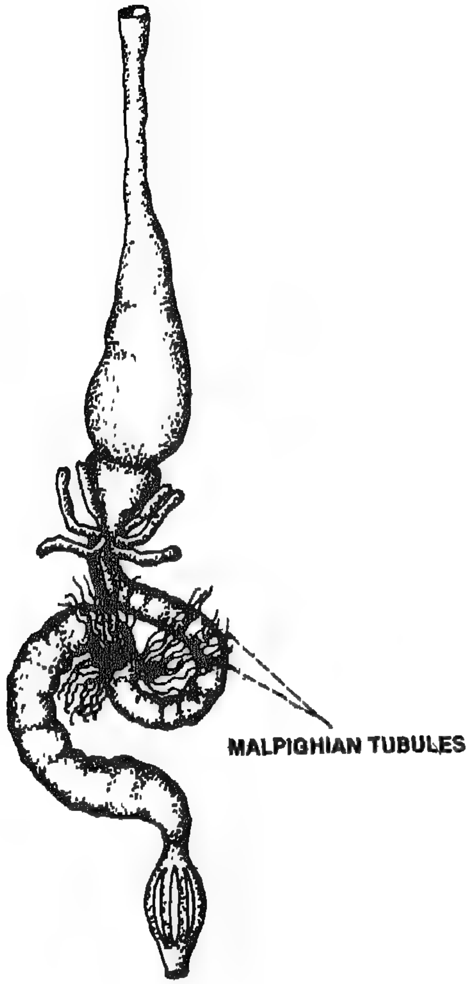


Fig 18 3 Excretory structure (Malpighian tubules) in insect

into the collapsible urinary bladder The urine is released periodically to the outside via the urethra

(Each kidney is made up of numerous coiled tubules known as nephrons) Their estimated number in each kidney of an adult human being is one million (A nephron is the functional unit of the kidney (Fig 18-6) One end of it is modified into a cup-shaped structure called Bowman's capsule, lined by a single layer of epithelial cells The rest of the nephron is differentiated into a coiled proximal convoluted tubule, a U-shaped thin loop of Henle, and a distal convoluted tubule. The distal tubule opens into a branching system of collecting tubules, major branches of which finally open into a funnel-shaped pelvis. The pelvis in turn collects urine formed in the nephrons and passes it into the collecting duct, the ureter Since blood brings the waste products to the kidney, each nephron must be closely associated with blood vessels The renal artery enters the kidney mass and breaks up into many smaller branches—the finest are called afferent arterioles (Fig. 18-6). Each of these enters the cup of the Bowman's capsule and branches into a tuft of capillaries, the glomerulus The capillaries join and rejoin to form the efferent arteriole which leaves the Bowman's capsule and breaks into a capillary network surrounding the rest of the

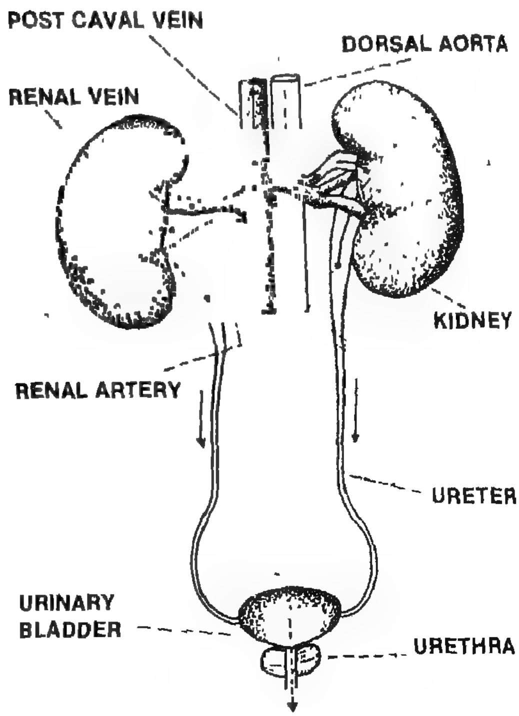


Fig 18-4 Excretory organs of man

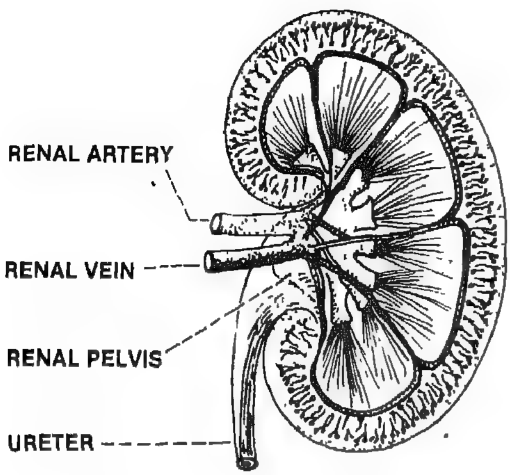


Fig 18-5 Vertical section of kidney

nephron Eventually, these capillaries reunite to form a renal venule, and several such venules rejoin to constitute the renal vein.

Urine formation in man involves three processes—glomerular filtration, selective reabsorption and tubular secretion Since the blood coming to the glomerulus is under sufficient pressure to cause an inward movement of a number of its components, practically all the blood plasma moves into the lumen of the Bowman's capsule High molecular weight plasma proteins, blood cells and some water are, however, retained in it, and this concentrated blood moves into the efferent arteriole. This step in urine formation is termed ultrafiltration Besides 180 litres of water removed by filtration per day, a large number of electrolytes, glucose, vitamins and other useful substances also cross the capsule The body, however, must not lose most of the filtered substances Hence, a process of reabsorption takes place in the convoluted tubule Reabsorption of solutes occurs by an energy requiring mechanism designated as active transport As the blood in the capillary network surrounding the convoluted tubule is more concentrated than the filtrate, water moves out of the tubule by osmosis This is a passive process Control is exercised at this stage so as to reabsorb only as much of a substance as needed. For example, if blood in the body has become dilute, reabsorption of water will be lessened so that blood will reach its normal concentration. A more dilute copious urine will be produced Thus, kidneys aid in osmoregulation Some substances which have not been filtered in the capsule pass into the tubule by tubular secretion Certain ions and other chemicals such as drugs are secreted in this manner

Thus the 180 litre glomerular filtrate produced undergoes several qualitative and quantitative changes in the nephron to form finally 0 5-1 0

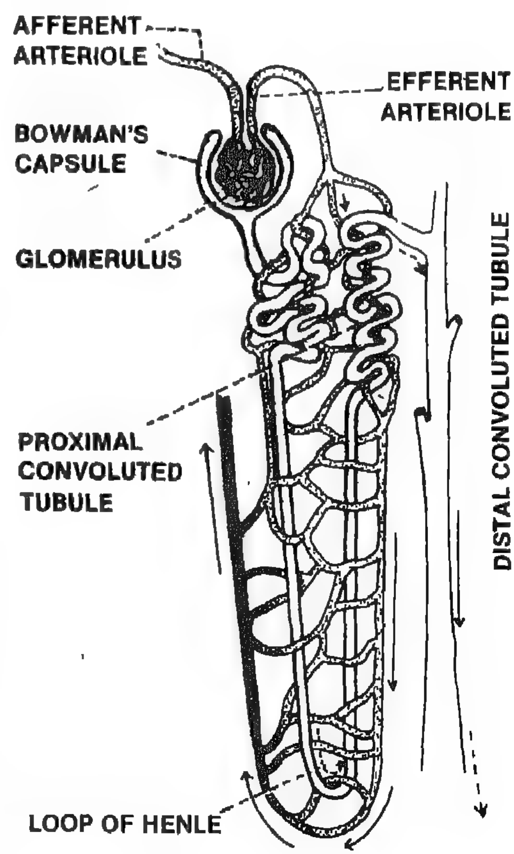


Fig 18-6 Structure of nephron

litre of urine per day. This urine trickles through ureters into the urinary bladder where it is temporarily stored and is finally eliminated from the body.

Besides kidneys there are four other major organs of excretion (a) Skin: Interspersed in the skin are the sweat glands which have three functions: (i) elimination of waste products such as urea; (ii) regulation of body temperature as evaporation of sweat contributes to heat loss; and (iii) removal of salt and water. (b) Lungs: If one considers carbon dioxide as a waste product, lungs qualify to be excretory organs Moreover, water is also lost along with expired air. (c) Intestine: The epithelial lining of the intestinal lumen helps to excrete salts which are removed from the body along with egested wastes (d) Liver Although not concerned directly in the disposal of waste materials, the liver serves important excretory functions Ammonia produced during the catabolic reactions is highly toxic to the body. Liver cells convert this ammonia into less harmful urea which can be stored for some time and periodically removed by the kidney Liver cells also break down haemoglobin of the old erythrocytes, and the iron is preserved for the synthesis of fresh haemoglobin. The rest of the molecule is converted into pigments that form components of bile which are removed from the body via the intestine. Liver also aids in detoxification of poisonous substances consumed along with food, for their subsequent removal.

Some Useful Terms

Bowman's Capsule The funnel-shaped anterior part of the nephron of vertebrate kidney enclosing a tuft of capillaries

Flame Cells An excretory organ consisting of a hollow cell with a bunch of cilia which work in its lumen, found in some invertebrates

Guttation The exudation of drops of fluid from an uninjured part of a plant, usually from the ends of the main veins of leaves

Hydathode A water-exuding pore, usually at the end of a vein of leaves of many plants

Latex A milky fluid, usually white or yellow, consisting of a mixture of proteins, carbohydrates, gums, which is present in many higher plants

Lenticel A small raised lens-shaped pore in the periderm, allows gaseous exchange between the interior of stem and the atmosphere

Malpighian Tubule Blind tubular fine excretory structure opening into the anterior part of the hind gut of insects, arachnids and myriapods

Mucilage Complex organic compound, related to the polysaccharides, of plant origin, and having glue-like properties

Nephridia (sing nephridium) Tubular excretory organs found in many invertebrates

Resin Hard, fusible and often brittle product from the secretion of some plants, soluble in certain organic solvents

Tannin A plant product which is a mixture of polyhydroxy benzoic acid derivatives; used for tanning leather

Ureter The duct by which urine is conveyed from kidney to the urinary bladder or cloaca

Urethra The duct by which urine is conveyed from the urinary bladder to the exterior

Things to Do

1 Examine the cross section of a leaf of *Ficus*, or the stem of *Tilia* or *Vitis* under your microscope and sketch the various types of crystals.

2 Collect and measure the urine eliminated by your body in a 24-hour period during summer and winter. Compare and comment on the results. Do you find any differences in the colour and quantity of urine after consuming (i) excessive amount of water, and (ii) beverages (tea or coffee)?

3 To a few drops of your sweat in a test tube, add a little silver nitrate solution Interpret the observations.

4 Pick up a drop of your sweat on the loop of a platinum wire Does the flame test indicate the presence of sodium?

Test Yourself

1 Distinguish between
   (a) nephridia and nephrons
   (b) ureter and urethra
   (c) efferent arteriole and afferent arteriole

2 Which contains less waste—the blood in the renal artery or that in the renal vein?

3 Match the words in Column I with those in Column II

Column I	*Column II*
(a) nephridia	(i) vertebrates
(b) glomerulus	(ii) amoeba -
(c) Malpighian tubules	(iii) fungi
(d) contractile vacuole	(iv) plants
(e) hydathodes	(v) insects
	(vi) earthworm

4 Fill in the blanks
   (a) The functional unit of the kidney is called __________
   (b) The proximal and distal tubules of the nephron are joined by the __________, __________, __________
   (c) Guttation occurs through __________
   (d) Kidneys aid in __________.

5 Name four organs which help in excretion Mention their functions briefly

Try to Answer

1 List the gaseous substances excreted by a flowering plant

2 Distinguish between egestion and excretion

3 What is the role of blood in excretion?

4 Persons suffering from very low blood pressure pass no urine Why? What suggestions would you offer for the removal of waste products from the blood in such a situation?

5 What would happen if the machinery for tubular reabsorption fails?

6 What do you expect if the waste products continue to accumulate in the body for several days?

7 Mention the steps in excretion which utilize energy

8 What would happen if you do not drink water for 24 hours in a hot summer month?

9 Tabulate the important excretory products in man, their sources, and organs responsible for elimination

10 "Man's kidneys are not adapted for a marine habitat or to life in very dry habitats " Evaluate the statement

19

Coordination

Hormones, Auxins, Gibberellins, Cytokinins, Abscisic acid, Phototropism, Geotropism, Brain, Spinal cord, Cranial nerves, Spinal nerves, Reflex action, Eye, Ear, Nose, Tongue, Skin, Endocrine glands—hypothalamus, pituitary, thyroid, parathyroid, adrenal, islets of Langerhans, ovaries, testes

LIVING things respond to their environment. Factors in the environment that bring about a response in an organism are called stimuli In other words, a stimulus is an external force whether mechanical, chemical, thermal or electrical, that is capable of generating a response How fascinating it is to observe: young birds balancing themselves on a metallic wire or branch, a porcupine using its quills for defence; a deer remaining alert to danger at all times; leaves of *Mimosa* folding up and drooping down on being touched; *Portulaca* flowers opening out beautifully in the bright sunshine; a plant turning its leaves and flowers towards light; and *Paramoecium* moving in the opposite direction on being touched with a needle. These are just a few striking examples of a perfect coordination between various stimuli and the characteristic reaction of living protoplasm to show diverse responses. In fact, the survival of plants and animals depends not only on the communication with the external environment, but also among the various parts of the body itself.

Plants

Let us first consider responses of plants to hormones (growth regulators) and to the environmental stimuli (tropic movements).

GROWTH REGULATORS

If you allow the seeds of maize or wheat to germinate and grow in dark and cut off 2-3 mm portion of the tip of the growing shoot, further growth stops If, however, the tip that was cut off is replaced back in position, the growth is resumed (Fig 19-1A) Don't you think that the tip exerts some influence over the lower part of the shoot, causing growth to take place?

Perform another, slightly modified experiment (Fig. 19-1B). Cut off the tip of the growing shoot and place it on a small block of agar jelly. (Dissolve agar-agar, a seaweed extract, in water. It solidifies to form a transparent jelly known as agar jelly.) After two hours, discard the tip and place the agar block on the cut-end of the shoot. The growth that was temporarily inhibited by the removal of the tip, is resumed You can now conclude that a growth-stimulating substance produced in the tip, has accumulated in the agar from where it diffuses back into lower part of the shoot Undoubtedly, this chemical substance appears to be produced by the cells of the tip Since it promotes growth, it is referred to as a growth hormone or growth regulator

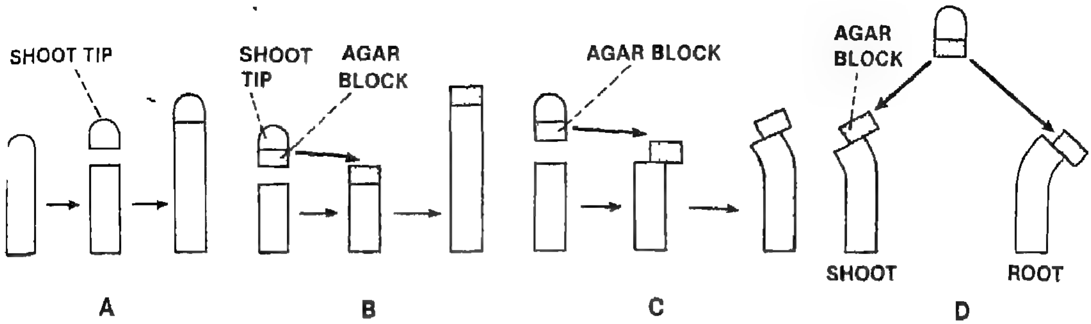


Fig 19-1 Experiments to demonstrate that hormone regulates growth in shoot and root

In still another experiment, cut off the tip of the shoot and then place it on an agar block as in the previous experiment (Fig 19-1C) After two hours put the agar block on the top of the cut shoot in such a manner that it covers only half the cut-end The side that is not covered by the agar block does not show any growth Instead, more growth takes place on the side that has the block on it The result is that the shoot bends away from the side In other words, it shows a curvature This ingenious experiment was performed on oat (*Avena*) by a Dutch botanist, F W Went in 1928. With greater insight he performed more experiments to demonstrate that the degree of curvature developed by a decapitated shoot was proportional to the concentration of hormone in the agar block

Went's studies led to elaborate chemical analysis of the growth stimulator by other investigators. These tests indicated that the growth stimulator was one of a group of plant hormones which are now called auxins

If the hormone is collected on the agar block as before, and the block then kept on the stump of a decapitated root, the reverse happens, i e., the root bends towards the side with the block on it (Fig. 19-1D) Although it suggests that auxins inhibit growth in the root, it promotes root growth at low concentrations. One of the most common auxins is indoleacetic acid (IAA)

Aside from their influence on shoot elongation, auxins influence other physiological activities such as (a) leaf fall, (b) fruit drop, (c) fruit development, (d) apical bud dominance, and (e) root development

Another group of hormones with enormous growth stimulating properties are the gibberellins A Japanese farmer noticed that some of the rice seedlings in his field were growing extraordinarily tall. He described them as 'foolish seedlings'. Subsequently the Japanese scientists discovered that this condition was caused by a fungus, *Gibberella fujikuroi* It secretes a mixture of related compounds called gibberellins They have a very powerful effect on growth These are produced by growing tips, and stimulate both cell division and cell elongation To demonstrate their action, treat a cabbage or dwarf wheat or bean plant every week with a dilute solution (10 mg/litre) of gibberellic acid for a month Leave some plants untreated as controls The plants treated with gibberellic acid will be significantly taller than the untreated controls (Fig 19-2) Thus the most noticeable effect of gibberellin is the stimulation of growth in dwarf varieties of certain plants Other characteristics of gibberellins are. (i) they stimulate flowering in rosette plants such as cabbage, (ii) they tend to inhibit growth of the main root, (iii) they inhibit the growth of adventitious roots; (iv) they stimulate the growth of side branches from lateral buds; and (v) they are also present in seed and

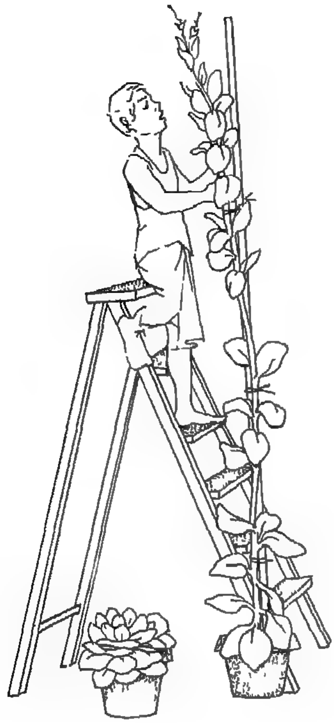


Fig 19-2 Untreated (A) and treated (B) cabbage plants exhibiting the effect of gibberellic acid

play an important role in breaking seed dormancy.

Still another group of active growth substances are known as cytokinins. They were first extracted from coconut milk but are now known to be of common occurrence in plants They are most abundant in tissues showing rapid cell division. They stimulate division only in conjunction with auxins Thus cytokinins and auxins interact in producing these effects. Cytokinins appear to play a role in the early development of the embryo and lateral buds

It has been discovered in recent years that abscisic acid, another growth substance, is responsible for bringing about the falling of leaves, flowers and fruits (abscission) Leaf fall is brought about by the development of a layer of cells at the base of leaf stalk With the passage of time, calcium pectate that forms the middle lamella of abscission cells, dissolves As a result, the cells separate from one another and the leaf falls off.

TROPIC RESPONSES

The simplest animals such as protozoans, sponges, and all plants are totally devoid of a nervous system. Despite this they are specialized to carry impulses and are capable of responding to factors in their environment Such simple responses are called tropisms; these may be either positive or negative Depending upon the nature of the stimulus in plants, a tropism may be called phototropism (movement in response to light), or geotropism (movement in response to gravity) Leaves and stems are positively phototropic, i e., they bend towards light, whereas roots are negatively phototropic On the other hand, roots exhibit positive geotropism by growing towards the gravitational pull, whereas stems react negatively to gravity

Animals

In higher organisms, certain cells referred to as neurons are specially designed to receive stimuli from the environment and show appropriate

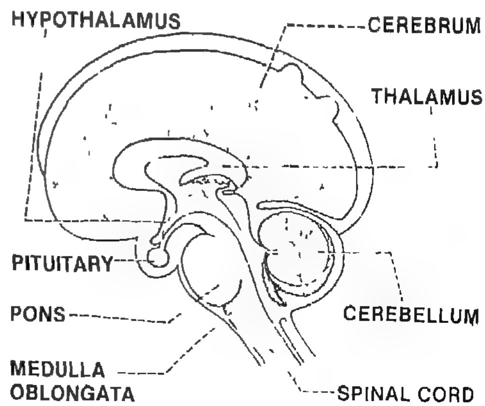


Fig. 19 3 Midsagittal section of brain showing its components

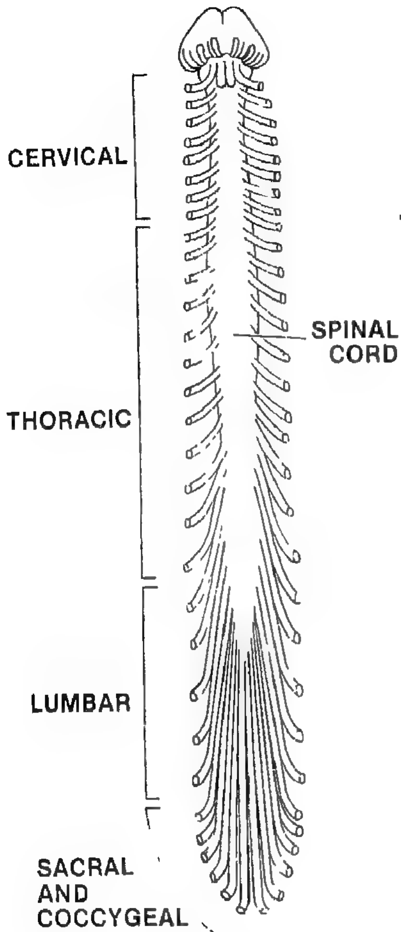


Fig 19-4 Spinal cord and spinal nerves

responses to these stimuli. In fact, billions and trillions of such neurons constitute the nervous system in mammals These neurons comprise two types of nervous system (i) central nervous system including the brain and the spinal cord, and (ii) peripheral nervous system consisting of nerve cells and fibres We shall now discuss these

CENTRAL NERVOUS SYSTEM

Brain In man it is located within the skull which is known as the brainbox or cranium. It is made up of a central core of tissue, the brainstem, and two outgrowths, the cerebellum and the cerebrum (Fig. 19-3). The bulk of the brain is formed by the cerebrum which overhangs the region of the brainstem. The portion of the brainstem nearest to the spinal cord is called the medulla oblongata Within this lie the control centres for respiration and circulation

Located just above the medulla are the pons and the midbrain The pons is situated in front of the cerebellum It aids in the regulation of respiration The midbrain is the continuation of the brainstem above the pons Anterior to the midbrain are two important areas of grey matter—the thalamus and hypothalamus The thalamus consists of a mass of nerve cells situated within the cerebral hemispheres Its major function is to act as a relay centre which sorts out sensory information such as pain, temperature, pressure and touch The hypothalamus is placed below, in front of thalamus, just above the pituitary gland It is composed of a number of groups of nerve cells. The hypothalamus possesses control centres that regulate hunger, water balance and body temperature It also plays an important role in the regulation of pituitary hormones and menstrual cycle.

The cerebellum is situated dorsal to the brainstem at the level of the pons. It has two large lateral masses, the cerebellar hemispheres. The main work of cerebellum is the coordination of muscular movement It also coordinates activities associated with the balance and equilibrium of the body For example, a person with cerebellar injury would walk in an uncoordinated fashion as if intoxicated

The cerebrum covers the top, back and sides of the brainstem and forms the largest part of the brain It is divided by a longitudinal groove into right and left cerebral hemispheres It has an outside layer of grey matter made up of billions of nerve cell bodies This layer is called cerebral cortex This covering does not fit like a smooth cap over the rest of the brain Instead it is folded so that ridges and depressions appear to increase the

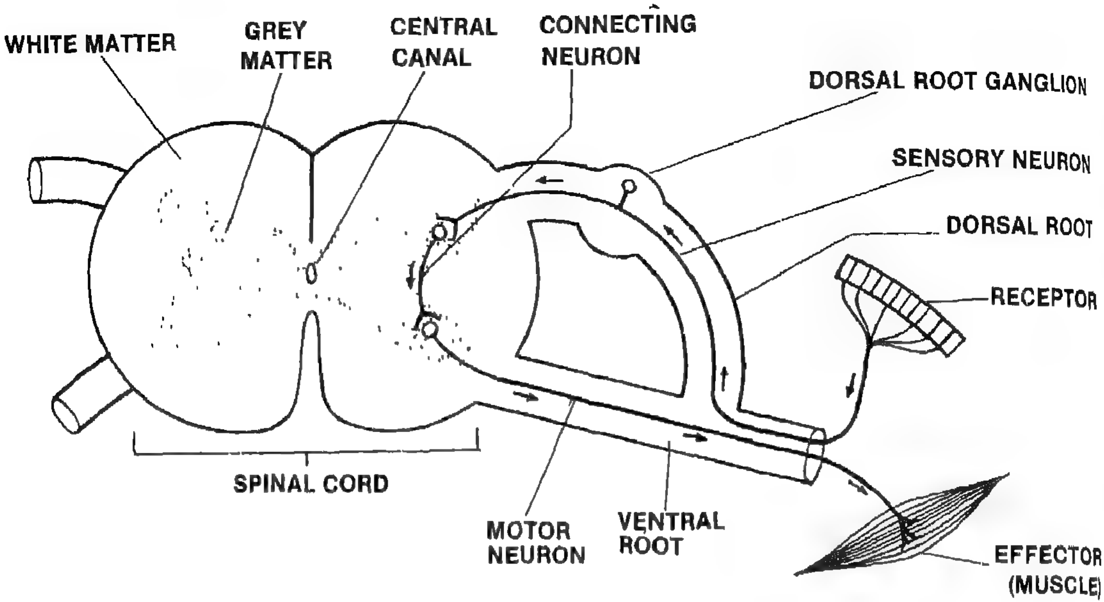


Fig 19-5 Spinal cord and route of typical spinal reflex (arrows)

surface area There are three major types of activities associated with cerebral cortex· (i) the mental activities involved in memory, intelligence, sense of responsibility, thinking, reasoning, moral sense and learning, (ii) sensory perception which includes the perception of pain, temperature, touch, and special senses of sight, hearing, taste and smell, and (iii) the initiation and control of the contraction of voluntary muscles

Spinal Cord It is a long, narrow, and almost cylindrical structure that extends from the brain to the bottom edge of the first lumbar vertebra (Fig 19-4) It lies within the neural canal of the vertebral column. A cross section of the spinal cord shows that it is divided into two regions, an inner H-shaped region of grey matter and an outer surrounding region of white matter (Fig. 19-5) The grey matter consists of cell bodies of thousands of neurons. The white matter is composed of myelinated nerve fibres that transmit information up and down the cord Surrounding the white sheath are three coverings known as the meninges. Dorsal and ventral grooves (fissures) divide the cord into the right and left halves A pair of spinal nerves emerges from the cord. These are connected to the cord by the dorsal and ventral roots

PERIPHERAL NERVOUS SYSTEM

The peripheral nervous system is formed by paired nerves extending out from the central nervous system It consists of (i) spinal nerves, (ii) cranial nerves, and (iii) the autonomic part of the nervous system

Spinal Nerves There are 31 pairs of spinal nerves They leave the vertebral canal by passing through the intervertebral foramina formed by adjacent vertebrae These include 8 cervical, 12 thoracic, 5 lumbar, 5 sacral and 1 coccygeal nerves (Fig 19-4) Just before the spinal nerve enters the spinal cord, it bifurcates In its dorsal branch (root), the sensory nerve cell bodies form a ganglion All the cell bodies of all the sensory or afferent neurons in the entire nerve are located in this ganglion The ventral branch (root) of the spinal nerve contains motor or efferent neurons

that carry impulses from the spinal cord to the muscles (Fig 19-5)

Cranial Nerves These nerves have their cells in the brain There are twelve pairs of them—some are sensory, some are motor, and those containing both sensory and motor fibres are referred to as mixed. There is no special difference in the functioning of the cranial and spinal nerves. These are called by two different names because of their different origin

Autonomic Nervous System This is organized into two distinct regions along the central nervous system forming the sympathetic system and the parasympathetic system While the former consists of the thoracic and lumbar ganglia, the latter is constituted by the remaining cranial and sacral ganglia The two systems act opposite to each other in their action to the muscles and glands they control

The autonomic nervous system controls the functions of the internal organs of the body automatically and unconsciously With the help of efferent neurons, autonomic nervous system sends impulses to the effector structures other than skeletal muscle These structures include smooth muscle lining the walls of digestive, respiratory, urinary and reproductive tracts, the smooth muscle of blood vessel and eye, the cardiac muscle, and both exocrine and endocrine glands

The autonomic nervous system controls (i) the rate and force of the heart beat, (ii) the secretion of the glands of the alimentary tract, (iii) the contraction of involuntary muscle, and (iv) the size of the pupils of the eyes

REFLEX ACTION

It can be defined as an involuntary response to a stimulus which is not under the control of the higher nervous centre, i e , brain For instance, while switching on the light or an electric iron or in the event of a finger coming in contact with a hot surface, the hand is withdrawn with a big jerk before one is able to correlate the particular experience This happens because the receptor cells on the skin perceive the message, which is then relayed by sensory neurons comprising the sensory nerve to the spinal cord (Fig 19-5). Once inside the cord, the message is sent back swiftly through one or more association neurons to the efferent or motor neurons present in the motor nerve to the particular muscle The contraction of the biceps pulls the hand away from the electric shock or hot surface It is only when the impulse moves from the spinal cord to the brain that one realizes what all happened

SENSE ORGANS

The brain receives communications from outside the body through five senses These senses and the special organs that are involved in perceiving them are sight—the eyes, hearing—the ears, smell—the nose, taste—the tongue, and touch and pressure—the skin

Sight and the Eye

The eye is a special organ of the sense of sight It is somewhat oval in shape and is situated in the orbital cavity

Structure Three layers of tissues comprise the walls of the eye These are (i) the outer fibrous layer—sclera, cornea, (ii) the middle vascular layer—choroid, ciliary body, iris; and (iii) the inner nervous layer—retina

Other structures include the lens, the aqueous humour and the vitreous humour (body)

The sclera, or white of the eye, is the tough outer fibrous coat It forms the outermost layer of tissue of the posterior and lateral aspects of the eyeball. Anteriorly it is continuous with a transparent window membrane, the cornea Behind the cornea, is the anterior chamber which is filled with a watery fluid called aqueous humour (Fig 19-6)

The choroid that forms the middle coat, con-

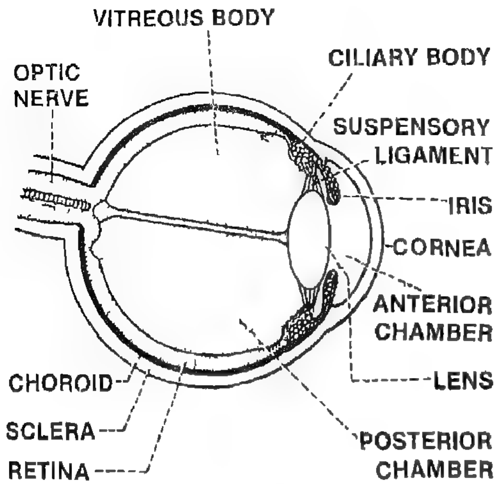


Fig 19 6 Section of eye showing its components

tains blood vessels and is deep chocolate brown. The ciliary body is an extension of the choroid anteriorly It is attached to suspensory ligament which, at its other end, is joined with the capsule enclosing the lens

The iris extends anteriorly from the ciliary body It is a pigmented muscular structure Depending on the particular pigment present in the iris, a person will have brown eyes, blue eyes, black eyes, etc. The pupil is the hole in the centre of the iris through which light passes The muscles in the iris determine its size The space bounded by the iris in front of the lens and suspensory ligament is called the posterior chamber

The lens is a circular biconvex transparent body enclosed within a capsule. It lies immediately behind the pupil The retina is the innermost nervous coat of the wall of the eye It is made up of several layers of nerve cells and nerve fibres lying on a pigmented layer of epithelial cells. The latter attaches it to the choroid. The light sensitive cells in the retina are the rods and the cones These names are derived from the rod- and cone-shaped nerve cells, respectively (Fig 19-7) The retina has a purple tint due to the presence of a pigment, rhodopsin or visual purple in the rods. This substance is bleached by bright light. Vitamin A is essential for its resynthesis All the fibres of the retina converge to form the optic nerve which eventually reaches the cerebrum of the brain The small area of retina where the optic nerve leaves the eye has no light sensitive cells This is called the blind spot The interior of the eyeball behind the lens is filled with jelly-like substance—vitreous humour—that prevents the walls of the eyeball from collapsing.

Physiology of Vision Visible objects reflect light rays which fall upon them. When an image is perceived, rays of light from the object pass through the cornea, aqueous humour, lens, vitreous humour, and then are brought to focus on the rods and cones of the retina As a result, nerve impulses are transmitted to the optic nerve

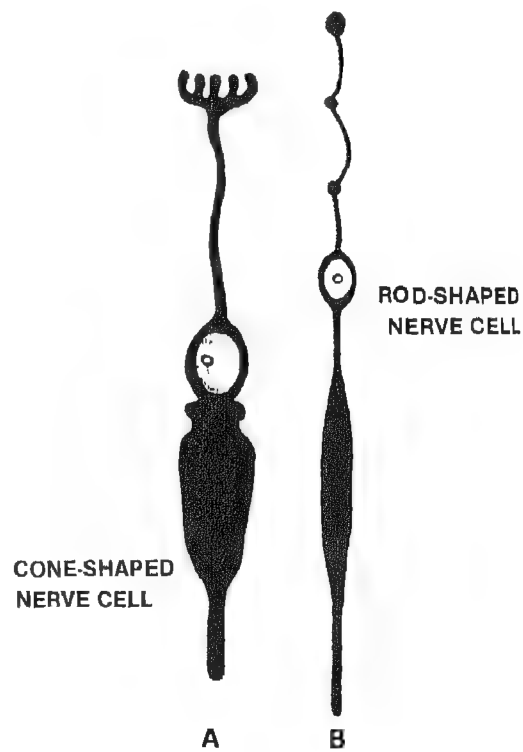


Fig 19-7 Cone- (A) and rod-shaped (B) cells in retina

and finally to the centres of vision in the cerebrum where sight is interpreted

Defects in Vision The normal eye is one in which parallel rays of light are focussed on the retina at a distance of about six metres Any abnormality in the shape of the eyeball or in the refractive surfaces, prevents this focussing of parallel rays and makes the eye defective. The most common defects are myopia, hypermetropia, presbyopia and astigmatism

Myopia (near sightedness) is caused either by too elongated an eye or too thick a lens In either case the rays of light converge too soon and the image falls in front of the retina This can be corrected by fixing a concave lens in front of the eyes so that parallel rays of light are focussed on the retina (Fig 19-8)

Hypermetropia (far sightedness) is the opposite of myopia It is either due to too short an eye or too thin a lens This causes the image to fall behind the retina. It can be remedied by fixing a convex lens in front of the eyes so that the incoming light bends toward the centre and brings the image forward to the retina (Fig 19-8).

Presbyopia or oldsightedness is a defective condition of accommodation in which distant objects are seen distinctly but near objects are indistinct It is treated by a convex lens

Astigmatism refers to unequal curvature of the refracting surfaces If the surface of cornea is not spherical, vertical lines will be bent to a different degree than horizontal lines and vision will be blurred It can be corrected by glasses that are curved in such a way as to compensate for the irregularity of the cornea

Hearing and the Ear

The ear is the organ of hearing It is divided into three parts—external, middle and internal 19-9)

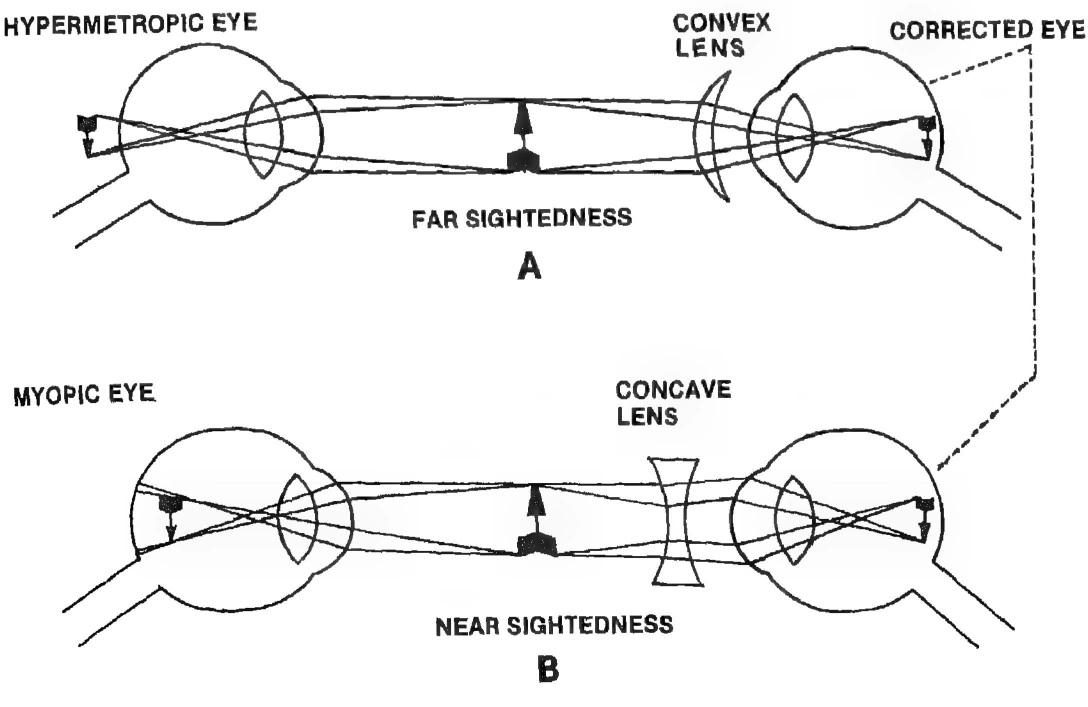


Fig 19-8 Causes of visual defects: hypermetropia (A), myopia (B), and their corrections by lens

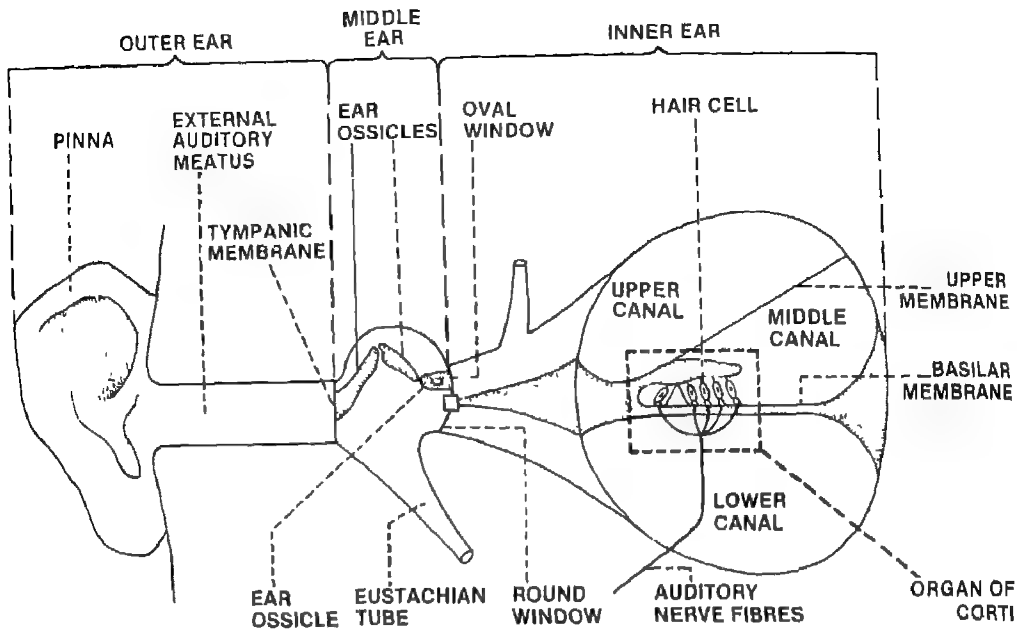


Fig 19-9 Basic structure and mode of action of mammalian ear

The external ear includes the head appendage, called the pinna, and the outer ear canal. The latter lies within the temporal bone The pinna is the expanded portion which projects from the side of the head It consists of cartilage covered with skin and helps to collect sound waves

The ear canal terminates at a membrane called the tympanic membrane or ear drum, which covers the opening into the middle ear It is an air-filled chamber. Air reaches this part through Eustachian tube which extends from the nasal part of the pharynx to the middle ear. The presence of air at atmospheric pressure on both sides of the tympanic membrane enables it to vibrate when sound waves strike it The opposite wall of the middle ear contains two membrane-covered openings which face the inner ear One of these is an oval window and the other just below, is a smaller, round window (Fig 19-9) Within the middle ear, there are three minute bones known as the ear ossicles They extend across the cavity from the tympanic membrane to the oval window

The internal ear contains the organ of hearing. It consists of two parts the bony labyrinth and the membranous labyrinth The former is a cavity within the temporal bone and is larger than the membranous labyrinth of the same shape which fits into it. This fitting arrangement is like a tube within another tube The spaces between the two labyrinths and the membranous labyrinth itself, are filled with different fluids The bony labyrinth harbours one vestibule, one cochlea and three semicircular canals in peculiarly shaped cavities The vestibule is the expanded part very close to the middle ear and contains both the oval and round windows The cochlea resembles the shell of a snail It is a spiral tube twisted on itself having a broad base and a narrow apex The three semicircular canals communicate with the vestibule Their position is such that each one is at right angles to the other two.

The membranous labyrinth is of the same shape as the bony labyrinth It is also divided into three identical parts a vestibule, a cochlea and three semicircular canals The inner space of the coiled cochlea is subdivided along its length into three channels—upper, middle and lower—by two membranes These are filled with a fluid The floor of the middle channel is the basilar membrane (Fig. 19-9). Upon this is located the primary hearing receptor, the organ of Corti This is lined with 4-6 rows of hair cells arranged along the basilar membrane. These cells bearing short, stiff cilia at their free surfaces are supplied with nerve fibres The hair cells and their nerve fibres form the true organ of hearing The nerve fibres combine to form auditory part of the eight cranial nerve. It finally reaches the hearing area in the temporal lobe of the cerebrum

Physiology of Hearing The sound waves collected by the pinna are concentrated and channelled through the outer ear canal towards the tympanic membrane These waves not only cause the tympanic membrane to vibrate but also put the ear ossicles into vibration. As a result, the last of the three ear ossicles rocks to and fro in the oval window. This carries vibrations to the internal ear. The rocking movement of the last ear ossicle sets up wave motion in the membranous labyrinth This stimulates movement of the fluid within, and eventually the sensory hair cells forming the organ of Corti, are stimulated. Consequently, nerve impulses are transmitted via the nerve fibres of the cochlear nerve which subsequently becomes the eighth cranial nerve. Some of the nerve fibres pass to the hearing area of the cerebral cortex It is in the hearing area of cerebral cortex that the nerve impulses are perceived as sound

The semicircular canals do not aid in hearing They are associated with maintaining equilibrium, i.e , posture and balance

Taste and the Tongue

Taste is a chemical sense. It depends upon the actual contact of molecules of the stimulating substance with the taste receptors in the mouth They react to chemicals in solution These taste receptors are in the form of taste buds which are mainly located within tiny projections on the surface of the tongue (Fig 19-10) They are also

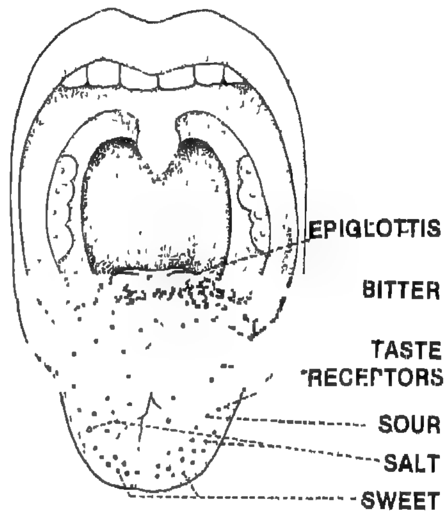


Fig 19-10 Sites of nerve endings of sense of taste in tongue sweet, salt, sour and bitter

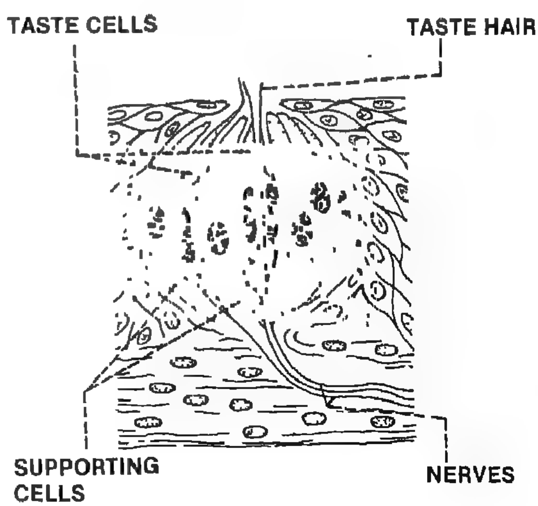


Fig 19-11 Section of taste bud

distributed in the roof of the mouth, throat and epiglottis A taste bud is an ovoid body It consists of an outer layer of supporting cells and contains, in the interior, a number of elongated cells. These cells end in hair-like processes which open to the outside through a tiny central pore at the surface of the tongue The receptor cells are linked with processes of sensory neurons which enter into the taste bud from below (Fig 19-11)

Different taste buds respond to diverse types of chemicals The four basic tastes are sweet, sour, salt and bitter The back of the tongue is more sensitive to bitter, the sides to sour and salt, and the tip to salt and sweet (Fig 19-10). The information is carried from the taste receptors to the cortex of the brain via seventh and ninth cranial nerves

Smell and the Nose

The receptor cells for smell are situated within a small patch in the upper portions of the nasal cavity Like the taste receptors, these are chemoreceptors, responding in this case to airborne gases or finely divided particles Scattered among the receptor cells are mucus secreting glands. The gas or the particle must first be dissolved in the mucus to be able to stimulate the receptor cells The dissolved substance then interacts with the hairs that extend from the receptor cells These hair-like processes communicate with the adjacent processes of neurons that combine to form the olfactory nerve Thus, following the stimulation of the receptor cells, impulses are transmitted along with the olfactory cranial nerve to temporal cortex This part of the brain contains the basic sensory area for smell

Touch, Pressure and the Skin

There are four kinds of receptors—the free nerve endings, touch receptors (Meissner's corpuscles), pressure receptors (Pacinian corpuscles) and nerve endings at the base of each hair on the skin, that respond to touch or pressure The two kinds of corpuscles are nerve endings surrounded in a

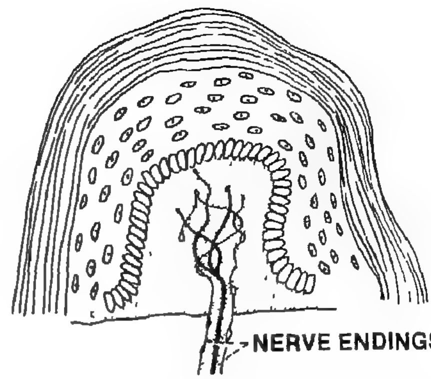


Fig 19-12 Meissner's corpuscle showing nerve endings wrapped in a sheath of connective tissue

sheath of connective tissue Meissner's corpuscles are located at the boundary of the epidermis and dermis (Fig 19-12). Pacinian corpuscles lie deep in the dermis These are activated by heavy pressure against the skin. The nerve endings of the various types of receptors are parts of the sensory nerves that extend all the way to the spinal cord After either the touch or pressure receptors are stimulated, impulses are sent up from the spinal cord to the medulla oblongata and then to the cortex of the brain via the thalamus

THE ENDOCRINE SYSTEM

Just think of a myriad of functions that the human body has to perform every moment for its smooth running This is made possible by an interplay of complex coordinated physiological processes which maintain most of the steady states or what is called the internal environment in the organism The constancy of the ionic composition and pH of the blood, water content, the arterial blood pressure, the body temperature, the blood glucose level are some of the typical features of the internal environment

The internal environment of the body is controlled partly by the autonomic nervous system and partly by the endocrine glands Unlike exocrine glands, these are ductless because the secre-

tions they produce do not leave the gland through a duct but pass directly from the cells into the blood stream. The secretions produced by endocrine glands are called hormones. These reach the distant target organs through blood stream and exhibit their specific effects

The endocrine system consists of the following glands the hypothalamus and the pituitary gland, the thyroid gland, the parathyroid glands, the adrenal glands, the islets of Langerhans in the pancreas, and the ovaries in the female and testes in the male (Fig 19-13).

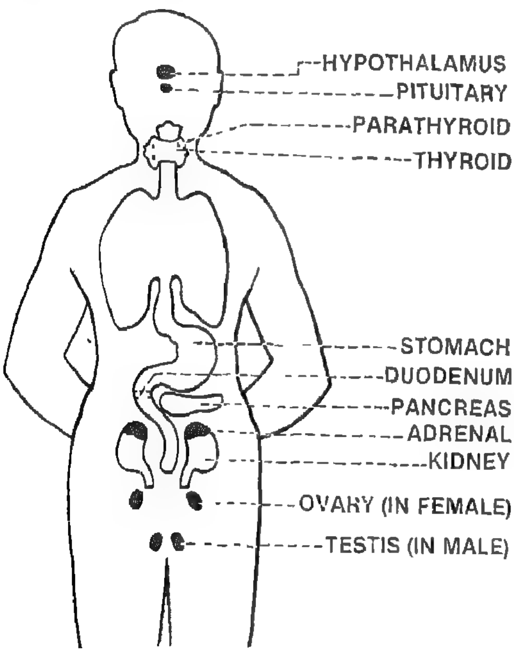


Fig 19-13 Position of various endocrine glands in human body

Hypothalamus and the Pituitary Glands The hypothalamus is located at the base of the brain The pituitary, also called hypophysis, hangs below the hypothalamus and is attached to the latter by the pituitary stalk It has three distinct parts. the anterior lobe, the middle lobe and the posterior lobe (Fig. 19-14)

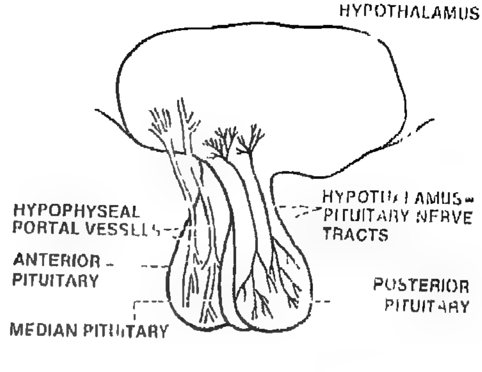


Fig 19-14 Structure of hypothalamus and pituitary

The anterior lobe secretes six hormones (i) Thyroid stimulating hormone (TSH) influences the structure and secretory activity of the thyroid, (ii) Growth hormone (GH) acts directly on all tissues and influences the growth of long bones, muscles and viscera, (iii) Adreno-corticotrophic hormone (ACTH) influences the activities of the adrenal cortex only, and the production of corticosteroids which are involved in defending the body against physiological stress such as exposure to prolonged cold; (iv) Follicle stimulating hormone (FSH) promotes the growth and maturation of follicles in the ovary, production of female sex hormones, oestrogen, and maturation of spermatozoa in the testis; (v) Luteinizing hormone (LH) stimulates the interstitial cells in the testis to produce male sex hormone, testosterone In the female, it causes the ovum to be released from the follicle within the ovary, the release of oestrogen, and formation of corpus luteum, (vi) Luteotrophic hormone (LTH) or prolactin that helps to maintain pregnancy, the secretion of the other female sex hormone, progesterone and stimulates the mammary gland to secrete milk.

The posterior lobe is in fact a kind of modified outgrowth of the hypothalamus. Modified nerve fibres run between the hypothalamus and this lobe of the pituitary. Two specific hormones are in fact secreted by these nerve fibres and later stored in the posterior lobe. They are released

from the pituitary only after receiving specific signals from the hypothalamus depending upon the needs of the body These hormones are: (i) Antidiuretic hormone (ADH) or vasopressin which controls water reabsorption in the kidney tubule and in this way regulates water and salt balance of body fluids, and (ii) oxytocin causes uterine contractions and active expulsion of milk during and after birth.

The middle lobe secretes only one hormone, Melanophore stimulating hormone (MSH). It is associated with growth and development of melanocytes which give the skin its colour

Association of Hypothalamus Pituitary From the foregoing account it is evident that the pituitary exerts a controlling influence over a number of other endocrine glands For this reason, until recently, it was considered to be the master gland of the endocrine system. However, of late, it is established beyond doubt that the pituitary, in turn, depends for its own activity entirely on messages sent from the hypothalamus The production of all the anterior pituitary hormones is controlled by messages from the hypothalamus. These messengers are called Releasing Hormones (RH) They pass from the hypothalamus to the anterior pituitary via tiny hypophyseal portal vessels (Fig 19-14). In fact there is a releasing hormone for each hormone produced by anterior pituitary such as TSH-RH, ACTH-RH, GH-RH, FSH-RH and so on.

Thyroid Gland It consists of two lobes, situated in the neck at the lower extremity of larynx (Fig 19-15) This gland makes use of dietary iodine which is utilized in the synthesis of its hormone, thyroxine Its primary effect on the body is to increase the rate at which cells burn their fuel, glucose, releasing energy. Thyroxine influences heat production and gets involved in overcoming the effects of exposure to severe cold. It is also essential for the mental and physical development Thyroxine also aids in the absorption of glucose from the small intestine

Parathyroid Glands These glands are four in number and lie embedded within the substance of the thyroid gland (Fig 19-13). They secrete the hormone, parathormone It helps to raise blood calcium

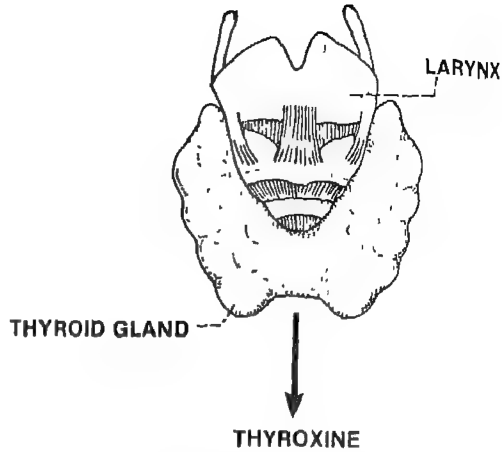


Fig 19-15 Thyroid gland

Adrenal Glands These are two small structures seated at the top of each kidney (Fig 19-13) These glands consist of an outer part called adrenal cortex and an inner adrenal medulla. Both function as separate endocrine glands

The main hormones secreted by adrenal cortex are corticosteroids in the form of gluco- and mineralo-corticoids. In addition, it also secretes minute quantities of male (testosterone) and female (oestrogen and progestrone) sex hormones. Glucocorticoids regulate the metabolism of carbohydrate, protein and fat. These hormones help to overcome the stress associated with surgical shock, pain, extreme emotional distress, severe cold and inflammation connected with infection. Stress is mainly overcome by the elevation of blood glucose level due to the conversion of protein into glucose.

The mineralocorticoids function at the kidney tubule to prevent sodium and water to pass in the urine and to increase potassium excretion The sodium ions are retained because they are very helpful for the activity of certain enzymes and for

the normal functioning of the nervous system.

The hormones produced by the adrenal medulla are adrenaline (= epinephrine) and noradrenaline (= norepinephrine) These hormones function in such a way as to help the body in handling emergency situations of extreme danger or fright. This is also referred to as 'fight or flight' response This is accomplished by increasing the heart rate, by raising blood pressure, by elevating blood glucose level and by selective dilation and contraction of blood vessels.

Pancreas The bulk of the pancreas consists of an exocrine portion which is represented by the pancreatic acini This part produces a variety of enzymes for digestion Round or oval patches of cells called islets of Langerhans lie scattered between the pancreatic acini Two types of cells, α and β are present in each islet in addition to a number of blood capillaries squeezed among these cells The β-cells dominate and secrete a hormone, insulin Another hormone, glucagon, is manufactured by the α-cells While insulin helps to lower the blood glucose level, glucagon functions to elevate it The interaction of these two hormones plays an important role in maintaining the blood glucose at a steady level

Inability to secrete sufficient insulin causes the most well-known disease, the diabetes mellitus The immediate result of low insulin is an abnormally high level of glucose in the blood—a condition called hyperglycemia Once the blood glucose exceeds a level beyond which the kidney fails to reabsorb it completely, its excess goes out in the urine This condition is also referred to as glucosuria

Ovaries Production of mature ova and the secretion of female sex hormones, oestrogen and progestrone, are the two important functions performed by the ovaries Once the primary follicle, under the influence of the anterior pituitary FSH, has grown into a mature follicle, it starts secreting oestrogen in increasing amounts Oestrogen controls the development of the secondary sexual characteristics of the female (see Chapter 20)

Following ovulation, i e , release of the ovum from the ovary, the ruptured follicle does not degenerate Instead, it grows itself into an endocrine structure called corpus luteum. It secretes another hormone, progestrone called pregnancy hormone (see Chapter 20)

Testes Like the ovaries, the testes have two jobs the production of sperms for fertilizing the ovum, and the secretion of male sex hormone, the testosterone It is secreted by the interstitial cells of the testes These cells are stimulated by the anterior pituitary hormones, LH or ICSH (Interstitial cell stimulating hormone) Testosterone controls the development of the secondary sexual characteristics of the male, viz , enlargement of penis and scrotum, pubic hair, deepening of the voice and development of sexual desire (see also Chapter 20)

Some Useful Terms

Adrenaline A hormone secreted by medulla of the adrenal gland handling emergency situations of extreme danger or fright, also referred to as epinephrine

Aqueous Humour Fluid occupying space between lens and cornea

Auxins Growth-regulating hormones of plants influencing shoot elongation and other physiological activities such as leaf fall, development of fruit and root

Basilar Membrane A membrane forming the base of the primary hearing receptor, the organ of Corti

Cervical Region Pertaining to neck region

Chemoreceptor A sensory end-organ capable of reacting to a chemical stimulus

Choroid The middle pigmented, vascular coat of the eye that lies between the sclera externally and the retina internally, prevents the passage of light rays

Ciliary Body A specialized structure in the eye connecting the anterior part of the choroid to the circumference of the iris

Coccygeal Region Pertaining to the terminal part of the vertebral column

Cochlea The anterior part of labyrinth of the ear, spirally coiled like a snail shell

Corpus Luteum An endocrine structure formed in the ovary after rupture of a Graafian follicle and subsequent expulsion of the ovum

Cytokinins A group of active growth substances in plants stimulating rapid cell division in conjunction with auxins

Epiglottis Thin flap of tissue that covers the opening leading into the wind pipe during swallowing

Eustachian Tube A canal connecting the middle ear to the pharynx

Ganglion A mass of nerve tissue which receives and sends out nerve fibres

Gibberellins A group of plant hormones with enormous growth stimulating properties; produced by growing tips and stimulate both cell division and cell elongation

Glucagon The hormone produced in alpha cells of pancreatic islets of Langerhans, causes breakdown of glycogen into glucose thus raising blood sugar

Glucosuria Excretion of glucose in urine as a result of high blood sugar level

Grey Matter Tissue abundantly supplied with nerve cells, internal to white matter in spinal cord, external in cerebrum and cerebellum

Hyperglycemia Having too much sugar in the blood, as in diabetes mellitus

Insulin A pancreatic hormone secreted in the beta cells of the islets of Langerhans, stimulates transport of glucose of cells to bring down blood sugar, used in the treatment of diabetes mellitus

Interstitial Cells (Syn *Leydig cells*) Occurring in angular spaces between the seminiferous tubules of testis and secreting male sex hormone, testosterone

Lumbar Pertaining to abdominal region

Melanophore A black pigment cell such as those formed beneath the epidermis in many animals

Meninges The three membranes covering the brain and spinal cord of a vertebrate

Neural Canal Canal found in vertebrae for passage of spinal cord

Occipital Pertaining to back part of head

Ossicles Small bones, particularly those contained in the middle ear, the malleus, incus and stapes

Oxytocin One of the posterior pituitary hormones in mammals functioning as a stimulus to produce uterine contraction and milk ejection

Pancreatic Acini Compound tubular structures comprising the exocrine part of the pancreas secreting a number of enzymes aiding in digestion in the duodenum

Pons White convex mass of nerve tissue at the base of brain which serves to connect various lobes of the brain, cerebrum, cerebellum and medulla oblongata

Primary Follicle A primitive ovum enclosed by a single layer of squamous cells, found in ovary in very large numbers before the attainment of sexual maturity

Releasing Hormones Factors or hormones in the form of messages produced in the hypothalamus, controlling the secretion of all the anterior pituitary hormones such as FSH-RH, TSH-RH

Sacral Pertaining to the hip region

White Matter Nervous tissue of the brain and spinal cord which consists mainly of nerve fibres having myelin sheaths

Things to Do

1 Select two flower pots with healthy chrysanthemum plants. Nip off the lateral flower buds in one plant and the apical flower bud in the other Record the differences in the size of the flowers produced on the plant after a few days in both the flower pots Interpret your observations

2 Place some bean seeds in a flower pot in various positions Observe the development of the roots and shoots. Explain these growth responses in terms of the influence of light and gravity

3 Stun a live frog by hitting its head against any hard surface. After the movements are paralyzed, cut away the upper jaw of the animal with the help of a large pair of scissors and a bone-cutter In other words, the frog has been decerebrated The animal is now said to be a spinal one because of its intact spinal cord Hold the animal head-side-down and wash off the blood under running tap water Immediately hang the spinal frog from an iron stand and observe what happens when (i) one of its hind toes is pricked with a needle, and (ii) a small piece of filter paper soaked in 5% acetic acid is placed on one of its thighs? What conclusions would you draw from these experiments?

4 Collect frog tadpoles from any pond near your locality Place them in a clean glass jar containing stored tap water and acclimatize them to laboratory conditions for 3-4 days Feed the tadpoles on small bits of green let-

tuce leaves washed thoroughly and wilted in warm water Clean the water frequently to remove debris and faecal matter with a pipette to prevent bacterial growth Take 10 tadpoles in two separate 250 ml beakers A and B, each containing 100 ml of stored tap water Introduce 2 mg of iodine by adding 0 2 ml of 1% alcoholic iodine solution (1gm iodine + 100 ml 70% alcohol), or 1 mg iodine plus 2 mg potassium iodide by adding 0 1 ml 1% aqueous iodine solution (1 gm iodine + 2 gm potassium iodide in 100 ml of distilled water) in beaker B only Run the experiment for a fortnight and carefully record observations Do the tadpoles remain exactly the same in both the beakers A and B during the course of the experiment? If not, what type of changes do you observe in tadpoles placed in iodinated water? At what stage of the experiment do these changes start taking place? How many days after are the tadpoles transformed into young frogs? What do you finally conclude from this experiment?

Test Yourself

1 Match the words in Column I with those in Column II

Column I	*Column II*
(a) auxin	(i) leaf drop
(b) adrenaline	(ii) blood sugar level
(c) gibberellin	(iii) calcium absorption
(d) abscisic acid	(iv) growth of apical shoot
(e) insulin	(v) breaking seed dormancy
	(iv) fear response

2 Tick the correct answer

(a) Auxins promote
 (i) flowering in rosette plant
 (ii) growth of lateral branches
 (iii) fruit development
 (iv) fruit fall

(b) The portion of the eye on which the image is formed is
 (i) iris
 (ii) retina
 (iii) lens
 (iv) cornea

3 Fill in the blanks

(a) The ear drum is also called the ___________
(b) ___________ and ___________ promote cell division in plants
(c) An involuntary response to stimuli is known as ___________
(d) Endocrine glands secrete ___________
(e) Iodine is necessary for the functioning of ___________

4 Write short notes on

(a) gibberellin (b) cytokinin (c) sense of taste (d) tropic responses (e) peripheral nervous system (f) reflex action

5 State the function of the following

(a) iris (b) tympanum (c) olfactory nerves (d) oestrogen (e) thyroxine

6 What is the autonomic nervous system and what is its function?

7 Mention two names for each of the three neurons in a reflex arc. Give three examples of reflex arcs in man.

8 Differentiate between the following pairs of terms

(a) myopia and hypermetropia
(b) glucocorticoids and mineralocorticoids
(c) white matter and grey matter
(d) stimulus and response
(e) phototropism and geotropism

Try to Answer

1 The rice seedlings infected with the fungus *Gibberella fujikuroi* grow rapidly to attain erratic patterns. Why?

2 Name some hormones which assume a direct or indirect role in (a) root initiation and growth, (b) stem initiation and growth; and (c) germination of certain types of seeds.

3 Name some plants whose stems are not geotropic. Can you offer any explanation for such behaviour?

4 List the external stimuli and their influence on the growth pattern of the plants.

5 What will happen if

(a) cells in the islets of Langerhans are worn out?
(b) the food one eats is deficient in the iodine content?
(c) the hypophysis suddenly stops secreting LH in the adult male?
(d) a person is suddenly confronted with a very dreadful situation?
(e) cerebellum is injured?

6 What will happen if you suddenly blow a loud horn when a person is crossing the road?

7 What is the significance of grey matter present in the middle of the spinal cord?

8 What is the endocrine control in the 'fight or flight' response? Explain.

9 Does the thyroid gland continue to secrete thyroxine continuously? If not, how is its production controlled?

10 Mention the exact location of each of the following controlling centres in the brain

(a) temperature
(b) hunger
(c) respiration
(d) water balance
(e) sight
(f) hearing
(g) menstrual cycle
(h) learning
(i) pituitary hormones
(j) equilibrium and coordination
(k) circulation
(l) sleep

11 Why do people in old age require glasses to read? How can you overcome this defect?

12 Why are hormones called chemical messengers? Justify your answer with two suitable examples.

20

Reproduction

Fission, Budding, Fragmentation, Vegetative propagation, Transformation, Conjugation, Fertilization, Alternation of generations, Pollination, Double fertilization, Seed formation, Dispersal, Genitalia, Spermatogenesis, Oogenesis, Sexual cycles, Embryo, Pregnancy

REPRODUCTION, or multiplication of an organism to produce offspring of the same kind, is a universal characteristic of all living beings It results in the continuity of life from one generation to the next It is accomplished by two methods asexual and sexual.

Asexual Reproduction

This type of reproduction concerns a single individual which produces new offspring exactly similar to the parent It does not involve the production or fusion of sex cells (gametes) Its most common example is fission which consists of a simple cleavage of the cytoplasm and nucleus of one cell into two almost equal daughter cells Each of these grows to a full size and then the process may be repeated This pattern is seen in unicellular plants (bacteria) and animals (amoeba) In yeast, a bulbous projection or bud, appears on one side of the cell. The nucleus divides and one of the daughter nuclei passes into the bud. The bud gets separated and in turn produces new buds This process is known as budding It results in the formation of two cells of unequal size. Multicellular plants can proliferate by fragmentation (or budding). In *Spirogyra,* the green filament breaks and each fragment grows to form an independent entity In *Marchantia,* gemmae produced in the cup-like gemma cups on the dorsal surface of the gametophyte, can germinate on a suitable substratum to give rise to new gametophytes On the other hand, in *Funaria* the young gametophyte or protonema, gives out a large number of buds, each of which forms a separate gametophyte.

Some multicellular animals also reproduce asexually by budding, or by fission In *Hydra,* for example, a small protuberance develops on the body wall (Fig 20-1). This grows in length and develops hypostome and tentacles at the free end With the formation of a basal disc at the point of attachment with the mother, it gets detached to lead an independent life Fission, another asexual mode of multiplication, is common in *Amoeba, Paramoecium* and *Hydra*

Many of the flowering plants, however, can reproduce asexually Some methods of vegetative multiplication are as follows.

(a) **Creeping stems** In creeping herbs, such as the grasses, roots arise at the nodes The internodes often degenerate and the separated nodes function as independent plants

(b) **Adventitious buds on leaves** As in

Fig 20 1 Budding in *Hydra*

Bryophyllum and *Kalanchoe*, large number of buds are produced on each leaf. These become detached and give rise to new plants

(c) **Bulbils** These are vegetative or floral buds, produced in the axil of leaves Bulbils drop from the plant and give rise to new individuals In pineapple each inflorescence ends in one or more reproductive buds which can develop into new plants

(d) **Bulbs and corms** These are organs of perennation consisting of modified stems. At the end of the growing season many smaller bulbs or corms are produced by the side of the older one. These give rise to new plants on resumption of the growing season as seen in gladiolus (Fig 20-2A) and onion (Fig. 20-2B)

(e) **Rhizome** In plants such as banana, ginger, turmeric, canna (Fig 20-3A) and iris (Fig 20-3B) the stem extends underground and is called rhizome. It keeps on giving out new plants from the buds produced on it.

Many of these methods of vegetative reproduction are routinely employed by man for artificial propagation of crop plants Sugarcane is cultivated by planting pieces of stem, each having a node and part of adjoining internode The bud present at the nodes grows out to form a new plant. Likewise, potato is grown from slices of the tuber bearing buds or 'eyes' on the tuber which give rise to new plants Ginger and turmeric are raised by sowing pieces of rhizome,

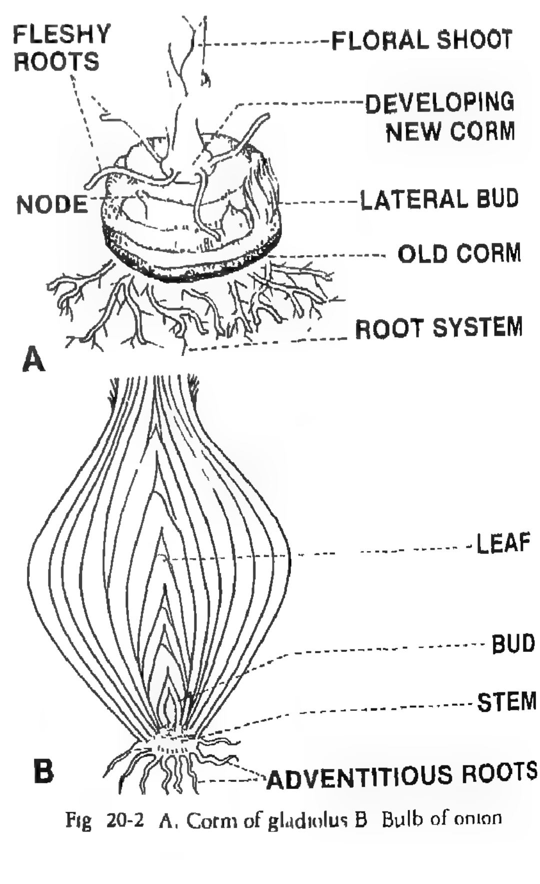


Fig 20-2 A. Corm of gladiolus B Bulb of onion

and tea and tapioca from stem cuttings.

Vegetatively grown crops have the advantage of being more uniform and similar to the parent stock. They require lesser time to grow to maturity, and flower and fruit simultaneously in the entire field They can withstand adverse conditions because the young seedling stage, which is most susceptible, is eliminated However, there are some disadvantages too. Vegetatively growing plants are often overcrowded. They gradually lose vigour and are prone to diseases

Sexual Reproduction

Barring blue green algae and some fungi, most plants and animals reproduce sexually. In this process, two haploid gametes are formed which fuse to give rise to a diploid zygote. The new individual produced from it combines the

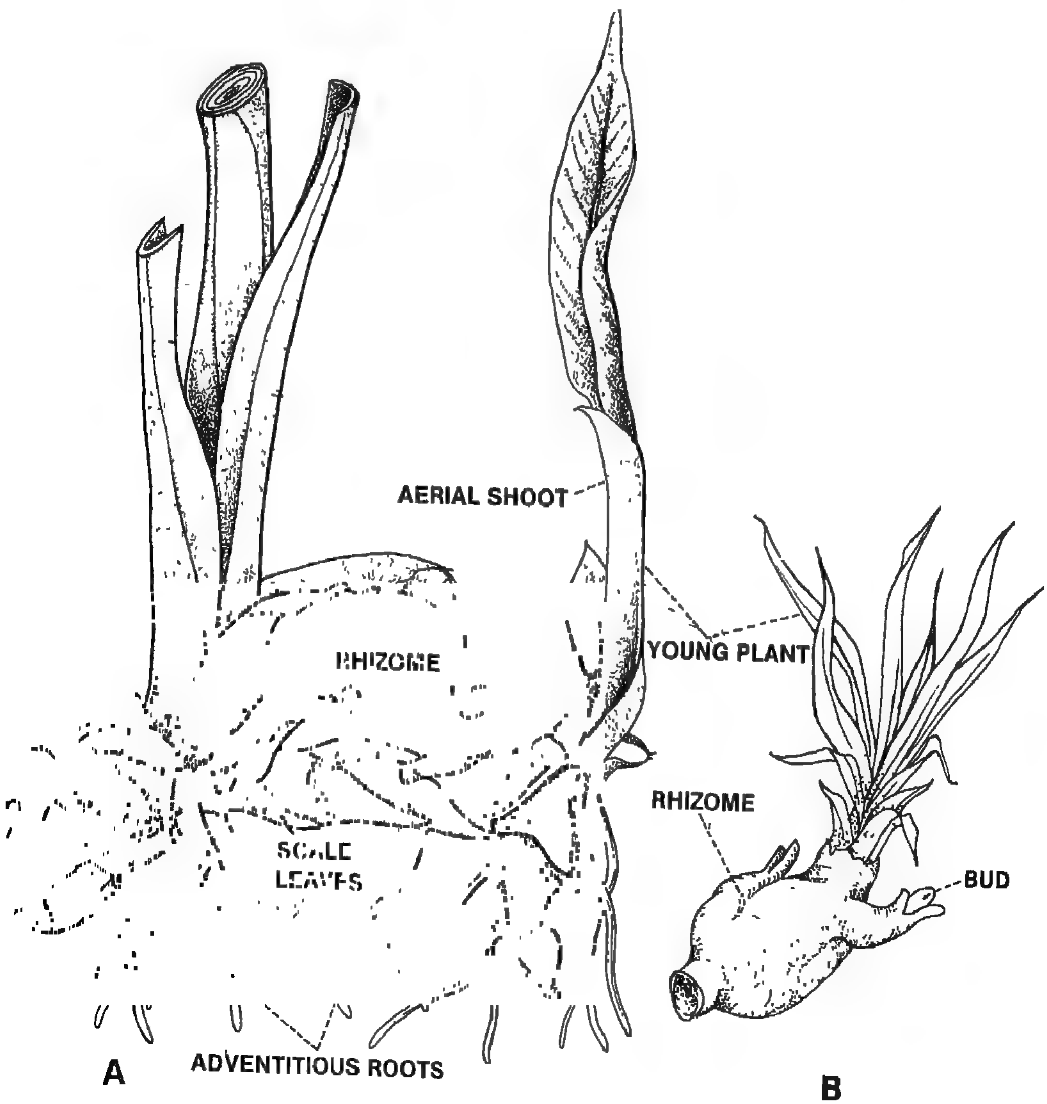


Fig 20-3 A Rhizome of canna B Rhizome of iris

hereditary information contributed by the two gametes The union of the two gametes is called fertilization As a result of crossing-over of genes in the chromosomes and random distribution of chromosomes during meiosis, the gametes produced are genetically heterogenous Sexual reproduction, therefore, leads to the creation of variation in characteristics of the succeeding generations of an organism

Different groups of plants present considerable diversity in their sexual reproduction In some bacteria transfer of genetic material occurs without the formation of gametes This involves incorporation of DNA fragments released from dead bacterial cells by simple absorption through the cell wall and plasma membrane of the living ones Another mode of sexual reproduction in bacteria is conjugation in which a donor cell directly transmits a part of its genetic material to a recipient cell

In lower plants such as *Spirogyra,* sexual reproduction occurs by conjugation Two different filaments of the plant come to lie close to each other and put forth small knee-shaped protuberances This is followed by the rounding up of the contents of each of the two conjugating cells into a spherical mass, and one of them is transferred to the other through the conjugation tube In the recipient cell, the two masses fuse to form a diploid zygospore which develops a thick wall. Meiosis occurs within the zygospore—three of the four nuclei thus formed degenerate, whereas the fourth gives rise to a new haploid filament In algae, there is thus, a regular alternation between the gamete-producing phase (of longer duration) and the spore-producing phase (of short duration) in the life cycle This is technically designated as the alternation of gametophytic and sporophytic generations

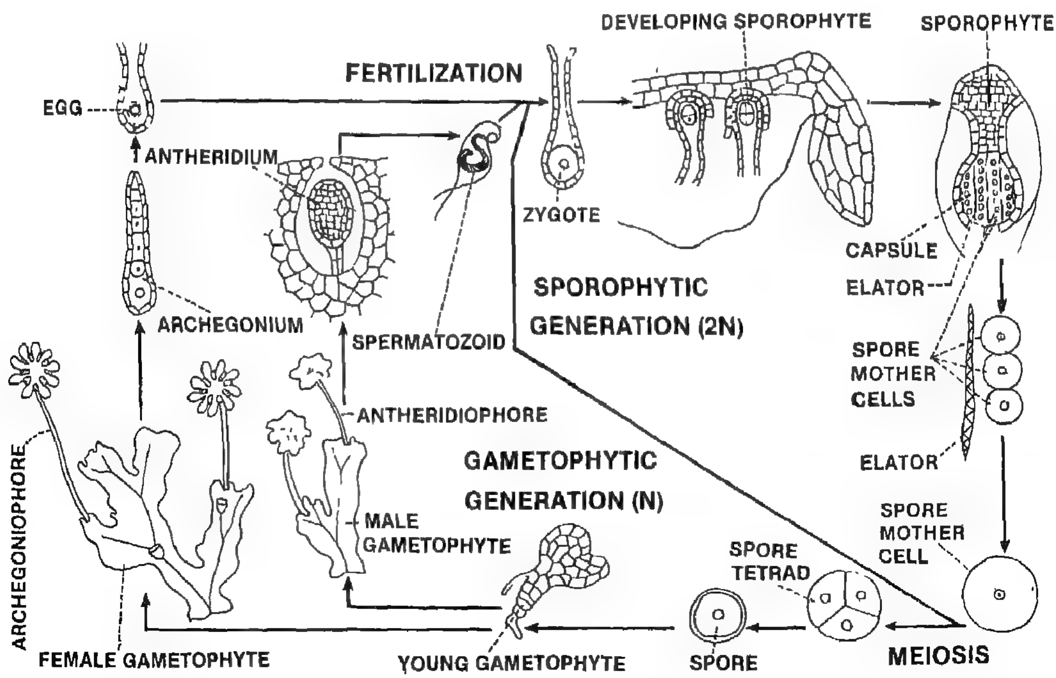


Fig 20-4 Life cycle of *Marchantia*

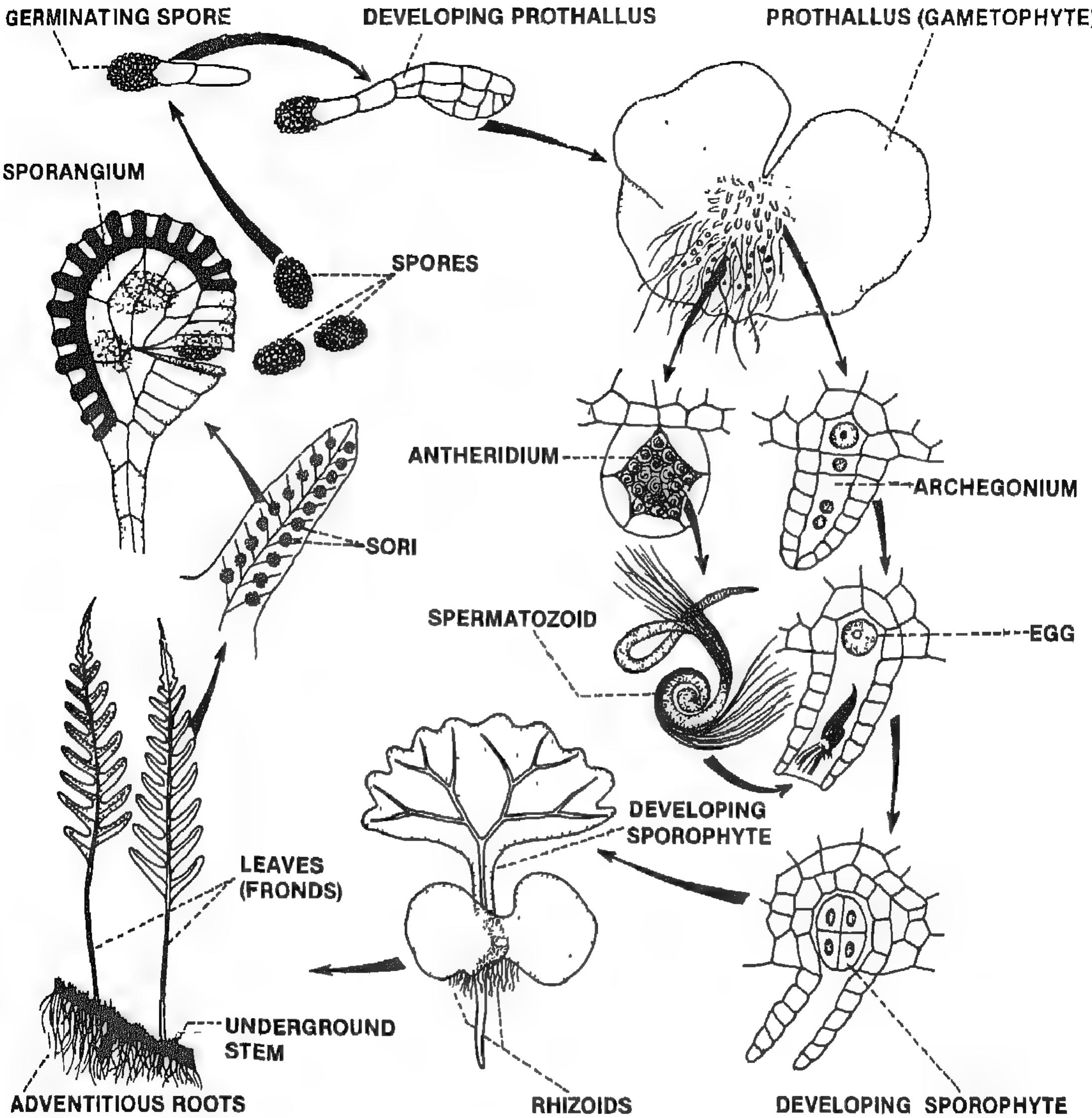


Fig 20-5 Life cycle of *Pteris*

Marchantia begins its life cycle as a tiny haploid spore which germinates to form a thallus representing the gametophytic generation The thallus bears the sex organs, antheridia and archegonia, on separate raised structures called antheridiophores and archegoniophores, respectively Haploid gametes or spermatozoids are produced in the antheridium, whereas the egg develops inside an archegonium The sperms swim through a film of water with the help of their flagella Fertilization occurs within the archegonium and results in the formation of a diploid zygote Unlike algae, in bryophytes the zygote undergoes several divisions to form the

sporophyte which remains attached to the gametophyte. The main part of the sporophyte is a sac-like capsule containing sterile cells, the elaters, and spore mother cells which after meiosis result in numerous spores, each capable of giving rise to a new thallus. Thus, in bryophytes there is an alternation of generations between a multicellular gametophyte and a multicellular sporophyte (Fig. 20-4). The sporophyte is, however, dependent on the gametophyte for nutrition.

Pteris has a sporophyte consisting of large leaves and underground stem with adventitious roots. The leaves (fronds) bear brownish reproductive structures called sori on their ventral surfaces. Each sorus consists of numerous sporangia in which meiosis occurs to give rise to haploid spores. The latter germinate in the soil to form small, green gametophytes called prothalli (sing. prothallus). Each prothallus bears antheridia and archegonia. Fertilization of the egg in the archegonium by a sperm released from the antheridium results in a diploid zygote. The new sporophyte is formed by divisions of the zygote. Thus, in pteridophytes, there is an alternation of generations between independent gametophytic and sporophytic phases (Fig. 20-5). However, in contrast to the non-vascular plants, in this group the sporophyte is the dominant phase of the life cycle.

The trend toward reduction of gametophytic generation continues in the gymnosperms and angiosperms. The main plant body in higher plants represents the sporophyte. In flowering plants, the gametophytic phase is extremely reduced and completely dependent on the sporophyte. You will read its detailed account later in this chapter.

Unlike plants, animals generally do not display an alternation of diploid and haploid generations. Meiosis occurs in certain specialized structures and directly results in the formation of gametes. Most of the animals produce heterogametes—the male gamete or sperm is generally small and motile, whereas the female gamete or egg is larger, immotile, and filled with stored food.

The sperms are produced in the testes by diploid cells called spermatogonia which are transformed into spermatocytes. Meiosis occurs in these to give rise to four haploid cells, the spermatids. Each spermatid develops a tail or flagellum and is then known as sperm. It can swim in water or moist surroundings.

The eggs are produced in the ovaries from oogonial cells. These are transformed into primary occytes which then undergo meiosis. In most aquatic animals and amphibians new oogonia are produced once a year. However, in reptiles, birds and mammals multiplication of oogonia occurs only once during the embryonic stage. Meiosis results in the production of eggs which enlarge considerably and store plenty of food material.

Fertilization involves fusion of the sperm and the egg. In most of the aquatic animals this occurs directly in water. Males and females of each species reach sexual maturity and release their gametes in water in close proximity. In insects, a special organ of the male organism is inserted into the female (copulation) to transfer sperms near the egg to bring about internal fertilization.

In amphibians such as frog, fertilization takes place in water. The male frog tightly embraces the female who discharges several thousand eggs into water. Following this, the male deposits sperms over the eggs. Reptiles, birds and mammals show a wide variety of adaptations to living on land or water. However, they all bring their gametes together by copulation followed by internal fertilization.

Most aquatic animals take no care of their eggs after they have been released and fertilized. However, in order to ensure their self-perpetuation, they lay their eggs in large numbers so that at least some of them will be fertilized and will grow to maturity. Terrestrial animals, however, provide some protection to

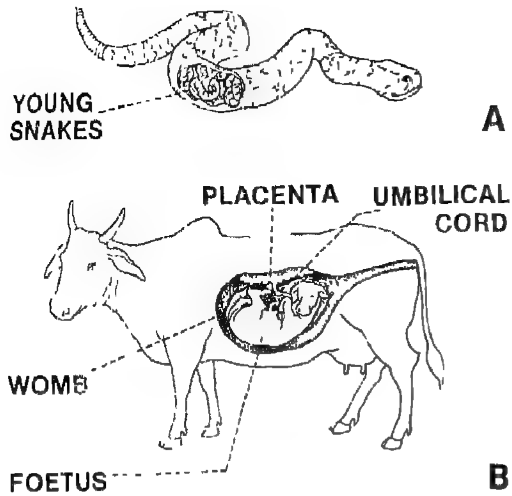


Fig 20-6 A Snake showing viviparity
B Cow with a young one within the womb

their developing embryos In insects the protection is provided by a waterproof covering around each egg or a group of eggs In reptiles the egg is deposited from the genital tract in a waterproof shell The eggs also store some food, or yolk, for nourishment of the young ones Though laid in suitable, warm locations, the eggs are subsequently abandoned by the mother. Birds also lay shelled eggs These are carefully tended by the parents in their nests Their eggs have abundant yolk Even after birth the young ones continue to receive parental care until they are self-sufficient However, some snakes such as rat snake and sea snake are viviparous and give birth to the young ones (Fig 20-6A)

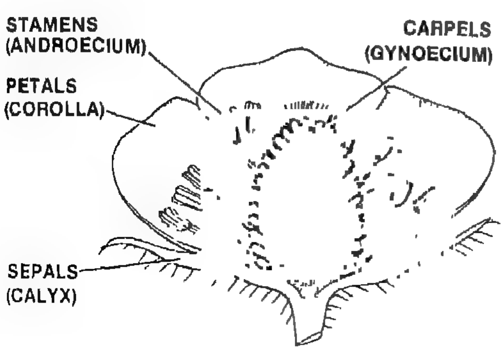


Fig 20-7 Longitudinal section of angiosperm flower

Mammals show elaborate care for their offspring The young embryo grows within the mother's womb and receives food and oxygen from the uterus with the help of the placenta and umbilical cord (Fig. 20-6B) After birth, the infant is provided nourishing milk secreted by the mammary glands of the mother The entire process of sexual reproduction in mammals is dealt with at the end of this chapter

Sexual Reproduction in Flowering Plants

Sexual reproduction is the most common method of multiplication of flowering plants This involves production of male and female gametes which fuse to form a zygote which develops into an embryo, thus initiating the next generation The seeds serve as a means of propagation and perennation of the sexually produced embryo

The plant body of an angiosperm is a sporophyte It develops through a period of continuous vegetative growth depending upon the habit of the plant. In annual species the vegetative phase is short and is followed by sexual reproduction and formation of seeds The parent plant dies thereafter This cycle is completed within one year. Some prolific weeds such as carrot grass (*Parthenium hysterophorus*) can complete four such cycles in a year. On the other hand, in trees the vegetative phase is extended and there is no flowering or seed formation in the first few years Subsequently the mature tree starts reproducing sexually year after year in a particular season

The angiosperm flower usually consists of four sets of floral parts· calyx, corolla, androecium and gynoecium (Fig 20-7) The latter two are directly concerned with the process of sexual reproduction. The androecium consists of a certain number of stamens (Fig 20-7), each of which comprises a lobed structure, called the anther, borne on a stalk or filament The anther is com-

monly a four-chambered structure each of which contains a number of microspore mother cells Meiotic divisions take place in these mother cells resulting in the formation of four microspores or pollen grains from each Thus, numerous microspores are produced inside every chamber of the anther. To begin with, the mature microspore (or pollen grain) is organized as a single cell It divides unequally to form a small lens-shaped generative cell and a large vegetative cell. Prior to or just after the release of the pollen grain from the anther, the generative cell divides to form two gametes or sperm cells This 3-celled structure represents the entire male gametophyte In a mature pollen grain the male gametes or sperms lie within the larger cell, the vegetative cell, which also stores some food material

The gynoecium or pistil is the female reproductive part of the flower. It can be generally distinguished into three portions ovary, style and stigma Inside the ovary are situated a fixed number (from one in each ovary in grasses and sunflower to thousands in cucurbits and poppy), of ovoid structures, the ovules. Each ovule consists of a dome-shaped core called the nucellus, surrounded by one or two envelopes known as the integuments A narrow canal, the micropyle, leads through the tips of the integuments and connects the ovarian cavity with the nucellus One of the cells of the nucellus acts as the megaspore mother cell. It undergoes meiosis and forms four haploid megaspores. Only one of these megaspores develops further, whereas the other three degenerate. By a series of three mitotic divisions in the surviving megaspore, an eight-nucleate gametophyte, designated as the embryo sac, is produced In the organized embryo sac there is one egg and two synergids at the pole near the micropyle. At the opposite pole are three antipodal cells The large cell in between is termed as the central cell which contains two polar nuclei. The embryo sac represents the female gametophyte The stage is now set for pollination and fertilization

POLLINATION

This process involves the transport of the pollen grains from anther to the stigma. If the pollen is transferred to the stigma of the same flower (as in China rose) it is termed as self-pollination. However, a vast majority of flowering plants reproduce by cross-pollination in which the pollen grains from a flower are moved to the stigma of another flower Cross-pollination is generally brought about by an outside agency, such as wind, water, insects, birds or bats

Pollination in grasses, acacia and mulberry is carried out by wind. The flowers are small and dull in appearance, but they produce millions of minute, dust particles like pollen grains To trap the wind-borne pollen, female flowers have prominent, sometimes brush-like or feathery stigmas Insect-pollinated plants, such as rose, salvia, orchids and sunflower, have large, showy floral parts and secrete nectar to attract insects Nocturnal insects are allured by fragrance, as in nightqueen Birds are also important pollinators of many tropical trees Silk-cotton tree and the coral tree are pollinated by birds which are attracted by red or pink, urn-shaped flowers having copious nectar Bats too pollinate some trees, e.g , the sausage tree, *Kigelia* Its flowers emit a foul smell which guides the bat to the dull but nectar-rich flowers

The biotic agents such as insects, birds and bats fly from one flower to another in search of nectar. Their bodies become dusted with the sticky, pollen grains of the flowers When such a pollen-laden animal comes in contact with the stigma of another flower pollination results (Fig 20-8). In nature each plant seems to have coevolved with a certain pollinator Often the pollinated plant and its specific pollinator are mutually dependent and cannot survive without each other.

Incidentally, wind-pollinated plants spread a profusion of pollen grains in the air. These get inhaled and cause allergic disorders such as asthma and hay fever

In submerged aquatic plants, pollination is

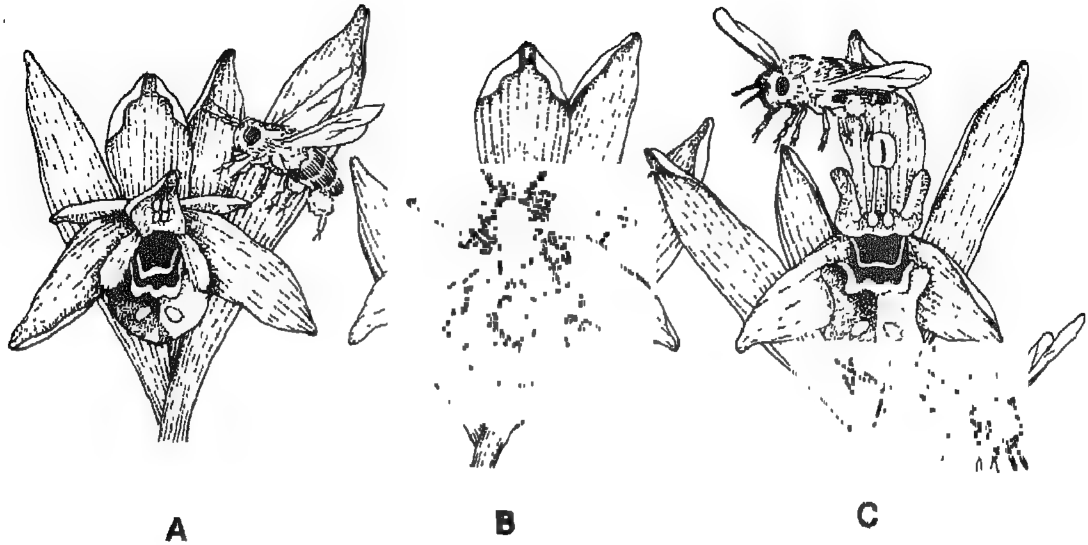


Fig 20-8 Pollination of flower A Insect visiting flower B Insect in touch with pollen grains C Insects moving away after pollination

brought about through the medium of water as in *Vallisneria* and *Hydrilla*. In *Vallisneria*, the minute male flowers are borne in an inflorescence on a short stalk, whereas the female flowers are solitary, each on a long, slender, coiled stalk This stalk uncoils to bring the flowers to the surface of water. The male flowers released from the inflorescence float on the surface and come in contact with female flowers The anthers dehisce and liberate the sticky pollen grains which get deposited on the stigma, thus effecting pollination

FERTILIZATION

The pollen grain germinates on the stigma and produces a pollen tube (Fig 20-9) The tube elongates and grows down the style into the ovarian cavity. Finally, it enters the micropyle and stops growing inside the embryo sac The pollen tube contains two sperms or male gametes (Fig 20-9) The tube ruptures in one of the synergids resulting in the discharge of male gametes (Fig 20-10) Ultimately, one gamete enters the egg and fuses with its nucleus to form a diploid zygote. The second gamete merges with the fused product of the polar nuclei (rarely it fuses with one polar nucleus and then with the other) to form the primary endosperm nucleus Angiosperms are unique in having such a process of double fertilization

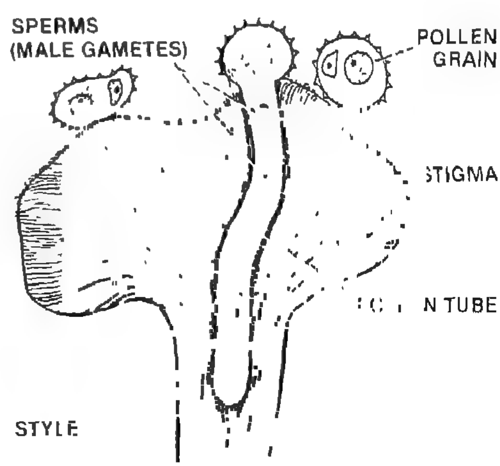


Fig 20-9 Germination of pollen grains on stigma

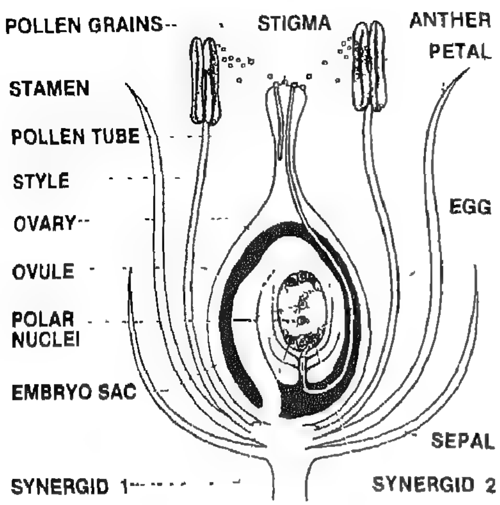


Fig 20-10 Longitudinal section of flower showing entry of pollen tube into synergid

FORMATION OF SEED

Following double fertilization a series of changes occur in the ovule which lead to the development of a seed. The zygote divides in an orderly manner and differentiates into an embryo The primary endosperm nucleus also divides repeatedly to form a parenchymatous tissue called the endosperm. The latter expands gradually and occupies the space formerly held by the female gametophyte and nucellus The ovule itself enlarges after fertilization so that the seed is many times heavier and larger The cells of endosperm accumulate food substances which are utilized for nourishment of the embryo. The mature ovule containing the embryo and endosperm constitutes the seed. In many seeds, the cotyledons which are a part of the embryo store the food. While these changes are in progress inside the fertilized ovule, the integuments differentiate into a protective seed coat.

The ovary also enlarges rapidly to form the fruit. The seeds and fruits of various plants show diverse adaptations for dispersal over a wide area When the seed falls on a suitable place, where moisture is available, it germinates. The embryo gives rise to the shoot and root system, and the endosperm meets the initial food requirements of the new seedling

Thus, in flowering plants the gametophytic generation is reduced to a brief, few-celled structure The gametophyte remains physically and nutritionally dependent on the sporophyte. The embryo represents the early stage of the next generation of the sporophyte The seed not only protects the embryo, but sometimes helps in its dispersal to a suitable place where it can grow The endosperm contains enough food to sustain the growth of the young seedling until it is large enough to expose its leaves for photosynthesis

DISPERSAL

Since most flowering plants are firmly rooted in soil, they need an effective method by which the offsprings can be disseminated to some distance away from the parent plant Distribution of seeds over a large area enhances the chances of survival and reduces overcrowding and competition among the seedlings for light, water and minerals The fruits and seeds exhibit various modifications to facilitate their transference.

Some fruits have a built-in mechanism for a forceful ejection of seeds In violet and the euphorbias, various layers of the fruit wall dry up at different rates This results in building up of a tension due to which the fruit explodes or ruptures The enclosed seeds are thrown more than a metre away In squirting cucumber the ellipsoidal fruit has many seeds which are surrounded by mucilaginous pulp Osmotic pressure builds up inside the fruit which, when detached from the stalk, squirts out the pulp and the seeds with great force

Most of the flowering plants depend on some outside agency, such as wind, water or animals, for their dispersal

Wind is one of the most important agents for dispersal of seeds The orchids produce profuse, minute, dust particle-like seeds which are blown

far and wide by the wind Seeds of milkweed and semul have tufts of hairs, whereas those of *Tecoma* and *Oroxylon* have wing-like outgrowths which help them to float in the air In maple, the fruit itself has bi-winged appendages with the help of which the fruit glides several metres away from the parent tree.

Many plants which grow within or near water utilize the aquatic medium for their dispersal The fruit of coconut is well-adapted to dissemination over long distances with the aid of sea currents Its exocarp is impervious to water, mesocarp has air spaces trapped between its fibres which make it buoyant, and the stony endocarp is protective The seed germinates readily when a fruit is washed up to a shore.

Animals also play an important role in the dispersal of seeds The fruits of some plants have spines or hooks with the help of which they adhere to the skin of animals and thus get carried over long distances. The fruit of unicorn plant, for example, is woody and covered with hooked spines (Fig 20-11) Two large, curved horns terminate the fruit The capsule opens by a longitudinal slit Such fruits fall on the ground and when an animal happens to step on them, the horns take a firm grip on the fetlock Because of the weight of the animal the slit opens wider and the seeds are sprinkled gradually over a large area

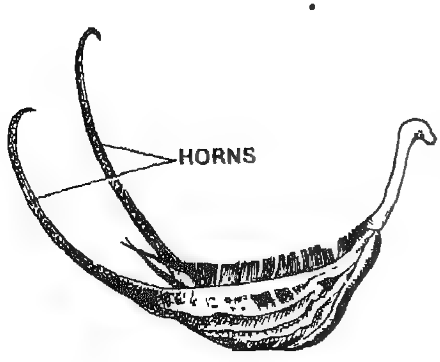


Fig 20-11 Hooked fruit of unicorn

Ants carry away the grains of several plants to large distances. The seeds of *Trillium* have oily appendages which ants eat and then discard the seeds. Such a seed can germinate if conditions are favourable Squirrels too have the habit of collecting fruits and seeds, some of which may germinate in the places of their hiding Birds are very efficient dispersal agents of many seeds of tropical plants. The fruits of plums, figs, grapes and guavas are eaten by birds The fleshy part of the fruit is digested, but the seeds pass out in the faeces Such seeds germinate easily utilizing the faeces as manure It is due to dispersal of seeds by birds that you often find the banyan and peepal trees growing atop buildings

Man has been responsible for the spread of many crops, forage plants, fruit trees and ornamentals He has purposely introduced seeds of many useful plants from one place to another However, seeds of numerous other plants get inadvertently transported by him Two very common weeds, *Croton bonplandianum* and *Parthenium hysterophorus*, got introduced into India only in recent years. Their seeds were mixed up with those of food grains imported from the United States Within a span of fifteen years these plants have become noxious weeds.

Sexual Reproduction in Mammals

You are probably aware that all vertebrates, including mammals, reproduce sexually and that the male and the female sex organs, the testes and the ovaries, respectively, are borne by separate individuals The specialized gamete-producing structures are collectively known as gonads Besides these, the reproductive system also consists of other accessory organs which help in the transportation, nourishment and maturation of the gametes

Male Reproductive System

The male genitalia in mammals consist of a pair of testes, ducts and accessory glands such as seminal vesicles, prostate and bulbo-urethral glands, and

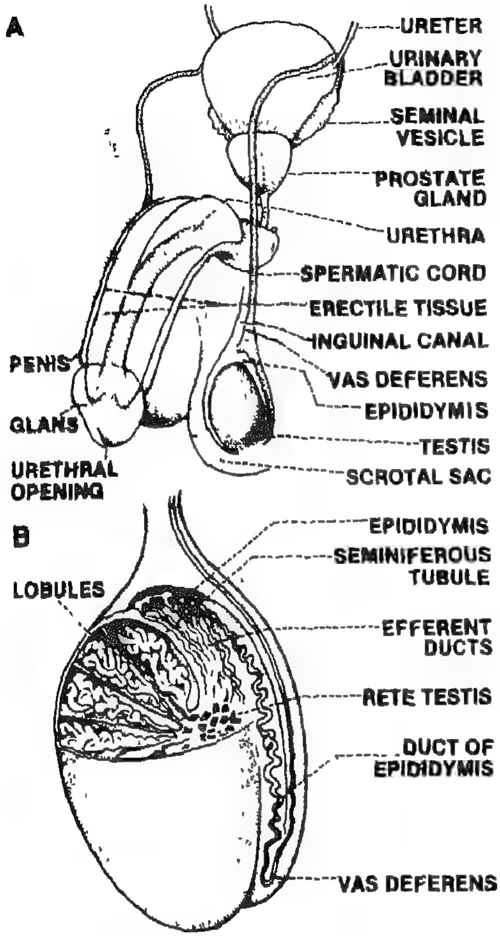


Fig 20-12 A. Reproductive organs of human male
B Cutaway diagram showing various parts of testis

the penis (Fig 20-12A)

Testes In man, these are ovoid, glandular organs of the size of a walnut. They are suspended in thin pouches of skin and connective tissue called scrotal sacs located outside the main body cavity Testes are concerned with the formation of male gametes, the spermatozoa These are produced only at a temperature 2 to 3°C lower than that of the body, maintained in the scrotal sacs

Each testis (Fig. 20-12B) is encased in a capsule of white fibrous connective tissue called tunica albuginea. The capsule is partitioned into 15-20 lobules and consists of two functional components. (a) seminiferous tubules which are highly coiled structures, involved in the formation of spermatozoa, and (b) interstitial cells (Leydig cells) which secrete male sex hormone, the testosterone Testosterone helps in the development and maintenance of the primary and secondary male sex characteristics and formation of spermatozoa The seminiferous tubules form a network at the anterior end of the testis, and have two types of cells—spermatogonia and Sertoli cells. The former are arranged in a specific manner within the tubule from the periphery towards the lumen representing various stages of development leading to the formation of spermatozoa The latter are tall cells that extend from the base to the lumen, support the spermatogenic cells around them and help in their nourishment

Spermatogenesis This term refers to the transformation of spermatogonia (male germ cells) into spermatozoa The testes begin to produce spermatozoa as soon as the organisms enter the reproductive phase and continue to do so throughout their life In man their production begins at puberty

The process of spermatogenesis is completed in four stages—proliferation phase, growth phase, maturation phase and transformation phase (Fig 20-13B)

1 *Proliferation phase:* During this stage, the spermatogonial cells have diploid number of chromosomes (46 in man) These undergo several mitotic divisions and increase in number. Some of these cells enter the next phase of development

2 *Growth phase* This stage can be distinguished from the earlier one by an increase in the dimensions of the nucleus and cytoplasmic contents of spermatogonial cells The spermatogonia of this intermitotic period are called primary spermatocytes

3 *Maturation phase·* The primary spermatocyte undergoes first meiotic division and

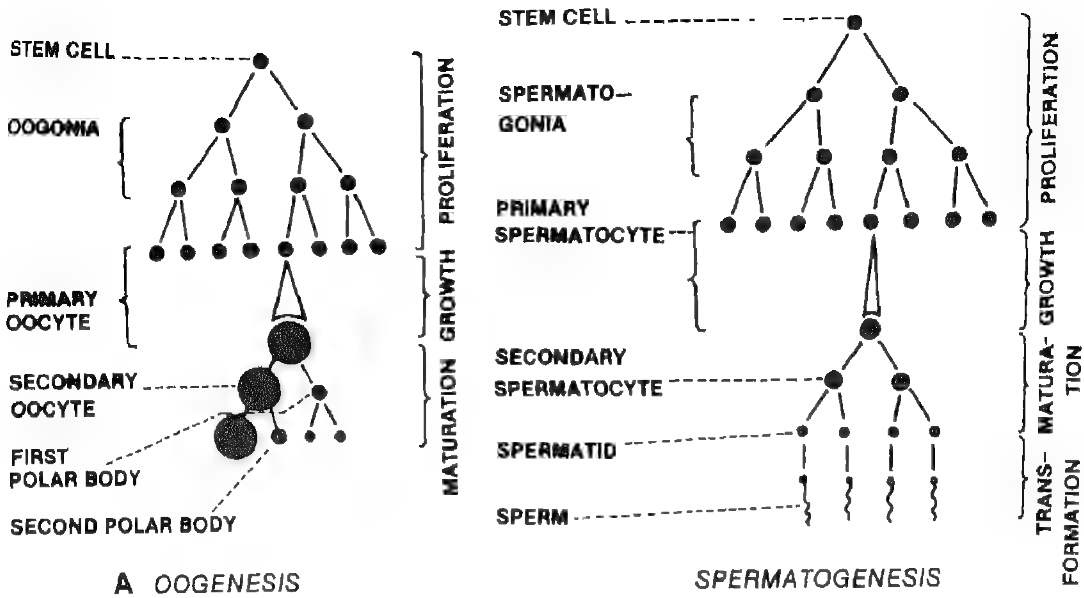


Fig 20-13 A Oogenesis B, Spermatogenesis

produces two smaller secondary spermatocytes The two secondary spermatocytes divide to give rise to four spermatids.

4 *Transformation phase:* During this final stage the spermatid acquires a tail and an anterior acrosomal cap (head cap) and is transformed into a spermatozoan.

Accessory Reproductive Organs

Epididymis It is a long (about 6 m in man), highly coiled, tubular structure firmly attached to the testis on its outer surface It stores the spermatozoa, makes them motile by the time they reach its posterior part, and serves as a passage for the transport of spermatozoa

Vas deferens After emerging from the testis, the epididymis becomes straight, increases in diameter and differentiates as a muscular tube called vas deferens It enters into the abdominal cavity through a wider tube called inguinal canal and terminates into an ejaculatory duct. Ejaculatory ducts join the urethra coming from the urinary bladder

Seminal vesicles These are convoluted sacs which open into the posterior end of the vas deferens They secrete seminal plasma which is viscous and forms about 40 to 80 per cent of the ejaculate.

Prostate glands Towards the posterior sides of the seminal vesicles, there is a pair of lobulated glands around the ejaculatory duct urethral junction The prostate glands open into the urethra through ducts. Secretion of these glands is alkaline and forms about 15 to 30 per cent of the ejaculate.

Cowper's glands Also known as bulbo-urethral glands, these are located quite close to the swollen end of the urethra They secrete a white, viscid, alkaline substance resembling mucus which acts as a lubricant and forms a gel in the ejaculate

Penis It is the external male genital organ The urethra passes through it and makes a common passage for the exit of urine and semen Around the urethra, there are three columns of spongy, erectile tissues which help in its erection. Exter-

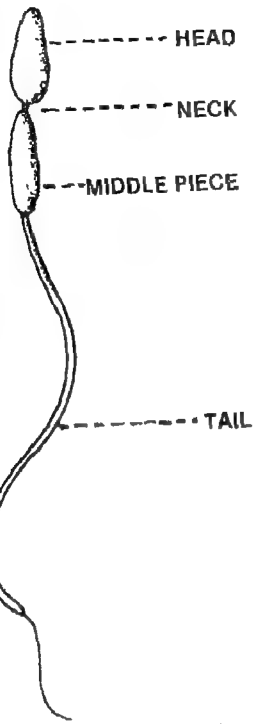


Fig. 20-14 Spermatozoan

nally it is covered by skin At the distal end of the penis there is a slightly bulging structure known as glans penis which is covered by a thin sensitive layer of skin called prepuce or foreskin.

Semen and spermatozoa During their transit through the seminiferous tubules and first half of the epididymis, the spermatozoa are immotile. They are activated and made motile by the secretion from the accessory reproductive organs These secretions are collectively designated as seminal plasma and are added to the spermatozoa during ejaculation The seminal plasma along with the spermatozoa constitutes the semen. The alkalinity of the seminal fluid maintained by the secretions of the prostate and Cowper's glands protects the spermatozoa from the acidity present in the male urethra and the female genital tract. A single ejaculate consists of 200 to 600 millions of spermatozoa contained in 4 to 5 ml of semen

The spermatozoan is made up of four parts head, neck, middle piece and tail (Fig 20-14) The head region contains a nucleus, covered by an acrosomal cap and very little cytoplasm along its periphery The neck connects the head to the middle piece and possesses a centriole The middle piece has mitochondria and a pair of fibrils which continue posteriorly into the tail part meant for the locomotion of the spermatozoan

FEMALE REPRODUCTIVE SYSTEM

The female sex organs of mammals not only produce the eggs but are also equipped to receive sperms from the male, provide suitable conditions for fertilization, and nourish the developing embryo They consist of two ovaries, Fallopian tubes, uterus, vagina and external genitalia (Fig. 20-15A, B)

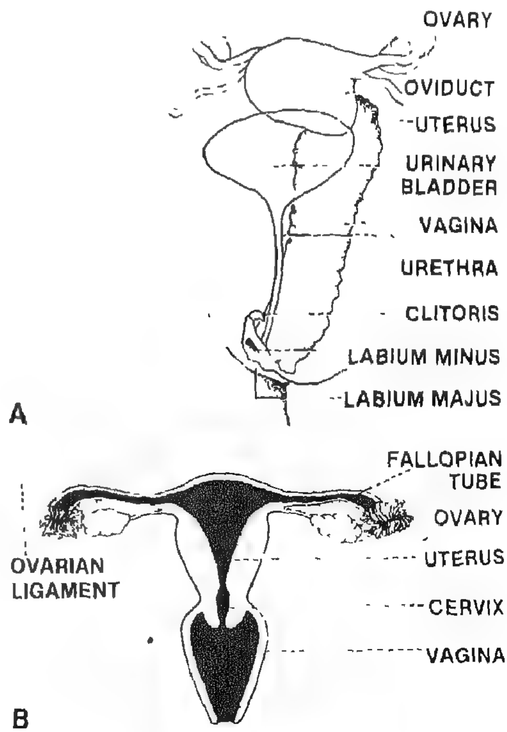


Fig. 20-15 A Reproductive organs of human female
B Diagrammatic sectional view of female reproductive system

Ovaries The human ovaries are located in the abdominal cavity, one on each side of the body They are of the shape and size of shelled almonds. Like the testes, they produce gametes (ova) as well as hormones (oestrogen and progesterone). They are covered by an epithelial layer called germinal epithelium Internally, the ovary is distinguishable into two parts—an outer broader zone, the cortex, and an inner narrower zone, the medulla The cortex is more cellular and is filled with spherical groups of cells, the ovarian follicles (Fig 20-16) Depending upon their stage of development, these follicles are classified into four types

1 *Primordial follicle:* It consists of an oocyte partly surrounded by follicular cells This type of follicle is mainly present during the embryonic stages of the female, and a few of them are seen after the birth.

2 *Primary follicle:* In this type, the oocyte is completely surrounded by a single layer of cells At the time of birth of the female child, in both the ovaries there are nearly 400,000 follicles in primordial and primary stages of development

3 *Vesicular follicle:* At this stage, several layers of follicular cells surround the oocyte With the growth of the follicle, a small cavity appears between the follicular cells which is filled with a fluid

4 *Graafian follicle:* With the multiplication of the follicular cells, the dimensions of the follicle increase. The ovum, surrounded by a few layers of cells, is then pushed to one side of the follicle On the outer side, the follicle is surrounded by a fibrous layer whereas the inner side is lined by a distinct cellular layer which secretes the hormone oestrogen This hormone is responsible for the female sexual characters that develop during puberty These include enlargement of the mammary glands, growth of hair in the arm pits and the external genitalia, widening of pelvis and deposition of fat in hips and thighs

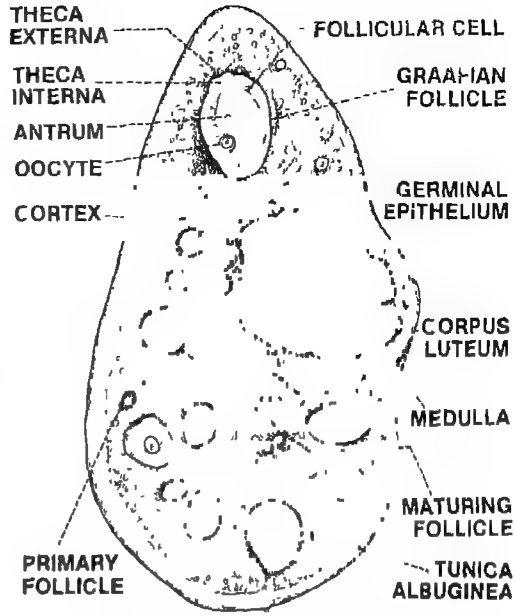


Fig 20-16 Cross section of mammalian ovary

Besides ovarian follicles, there is another distinct secretory structure present in the ovaries This is termed as corpus luteum (yellow body) and is produced by the transformation of a Graafian follicle after the release of its ovum. It secretes the hormone progesterone which helps to maintain pregnancy and to prevent menstruation during this period.

Oogenesis This term refers to the transformation of oogonia (female germ cells) into ova. The ovaries begin to produce one mature egg every month, at puberty, and continue to do so until menopause (up to the age of 45-55 years) when they shrink and stop releasing eggs.

The process of oogenesis is completed in three stages—proliferation phase, growth phase and maturation phase (Fig 20-13A).

1 *Proliferation phase:* The oogonial cells which have a diploid number of chromosomes undergo several mitotic divisions in the foetus up to six months and multiply in number

2 *Growth phase.* At this stage, the cytoplasmic

contents and the nuclear size of the oogonium increase, it becomes transformed into a primary oocyte. The growth phase is also completed during the foetal life In fact, the ovary of a new born female infant contains numerous primary oocytes surrounded partly or completely by follicular cells

3 *Maturation phase.* The primary oocyte undergoes meiosis in two steps. The first reduction division takes place when it is in the Graafian follicle. It leads to the formation of two unequal daughter cells—the larger constitutes the secondary oocyte, whereas the smaller, consisting mainly of the nucleus, forms the first polar body, that subsequently degenerates. An ovum and a second polar body result from the second meiotic division or second maturation division prior to fertilization. Like the first, the second polar body also disintegrates after some time Thus, a single mature cell is produced from one primary oocyte.

Accessory Reproductive Organs

Fallopian tubes The eggs are discharged into the body cavity and then pass through a pair of highly coiled tubes which lie between the ovaries and the uterus Structurally, the free end (towards the ovary) of each tube is expanded into a broad funnel-like fimbriate body At the time of release of ovum from the ovary (ovulation), the funnel comes close to the ovary to facilitate the entry of the egg into the Fallopian tube, where it is fertilized.

Uterus It is a large pear-shaped, hollow, muscular organ, measuring about 7 5 x 5 0 x 2 5 cm (but stretches to nearly four times during pregnancy), and connected to the Fallopian tubes It consists of an upper portion, the body, and a lower section, the cervix The body of the uterus is composed of three coats—endometrium (the innermost), myometrium (the middle) and perimetrium (the outermost). While the endometrium is provided with specially designed blood vessels and uterine glands, the myometrium has layers of smooth muscle fibres, and the perimetrium has serous membrane and thin connective tissue Cervix is mainly a sphincter muscle that closes the uterine lumen and prevents the passage of foreign particles into the uterus The important functions of the uterus, i e , menstruation, pregnancy and labour, are performed by the various layers

Vagina It is a single, straight, collapsible, musculo-membranous tube, about 9 cm long, connecting the cervical canal at the upper end with external genitalia at the lower end, where its orifice is partially closed by a thin fold of mucous membrane in the virgin state called hymen Internally it is lined by a highly folded epithelial layer Vagina receives the seminal fluid from the penis during sexual intercourse, secretes acidic fluids which constitute the first barrier to sperm transport It also serves as the lower portion of the birth canal and acts as a duct for uterine secretions and menstrual flow

Vulva The female external genitalia comprises mons veneris (pubis), labia majora, labia minora, clitoris, urinary meatus, vaginal orifice, and Bartholin's glands. On the pubis region, coarse hair appear at puberty and persist throughout life While the labia majora (large lips) is a pair of thick folds of skin containing hair follicles, sweat glands and sebaceous glands, the labia minora (small lips) are two small folds of mucous membrane situated on the inner side of labia majora, devoid of hair follicles and glands. At the upper end, the folds meet to form a thin covering, the prepuce The clitoris is a small erectile tissue located at the junction of the labia minora, below the prepuce. Like the foreskin of the glans penis, the prepuce covers the clitoris. The urinary meatus is a small opening of the urethra below the clitoris, and the vaginal orifice is the external opening of the vagina through the hymen There are two bean-shaped glands on either side of the vaginal orifice Each of this Bartholin's glands (comparable to the bulbo-

urethral glands of the male) open into the space between the hymen and the labia minora through a duct and secrete lubricating fluid

Sexual Cycle

In mammals, the females show cyclical changes in the ovaries, uterus and vagina These are of two types One is known as the oestrous cycle and the other as menstrual cycle

Oestrous Cycle

The females of non primate mammals experience a rhythmic change in the intensity of sex urge, and levels of hormone secretion. During the period when their sexual desire is maximum, they are most receptive to the males for mating and are said to be in heat or in oestrus This time is close to ovulation Although many mammals have only one or a few oestrous periods each year, some such as rats and mice, have it as often as every four or five days

Menstrual Cycle

The reproductive cycle of human females and of other higher primates differs from non primates in two ways First, the receptivity of the female is more or less continuous Secondly, there is bleeding or menstruation phase which is not met with in the non primates.

In human females, the duration of the menstrual cycle is about 28 days with inner variations. This cycle is divided into four phases—menstrual phase, proliferative or oestrogenic phase, ovulatory phase, and progestational or luteal phase (Fig 20-17)

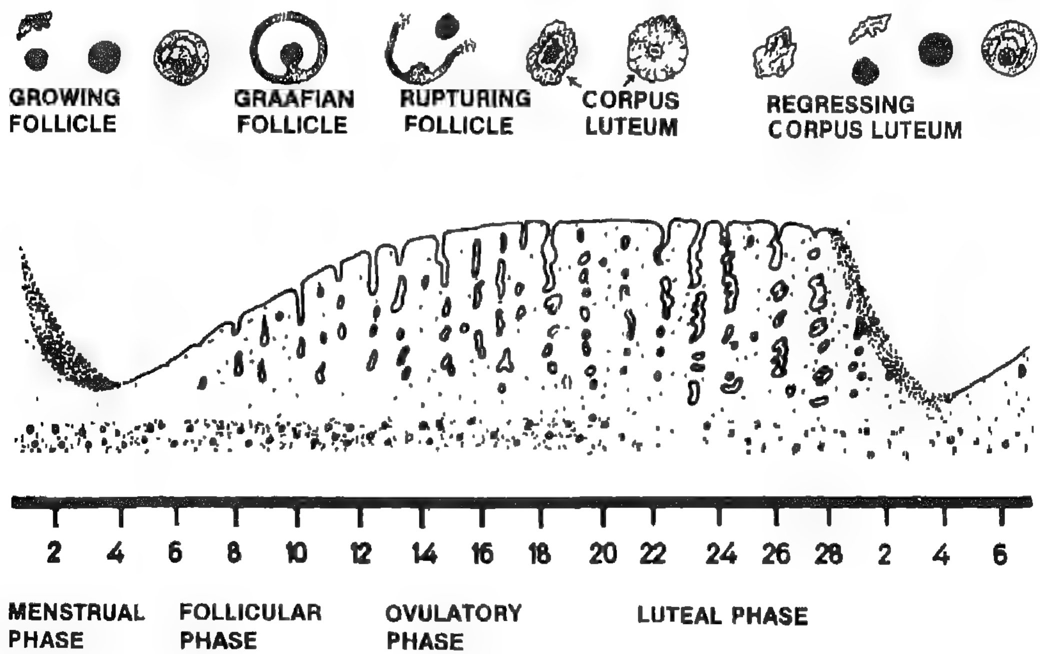


Fig 20-17 Uterine changes in relation to follicular changes during menstrual cycle

1 *Menstrual phase* It lasts for 3-5 days during which blood is discharged out. The bleeding is caused by the rapid regression of the uterine lining, rupturing of its blood vessels and sloughing away of portions of endometrium The day of the beginning of menstruation is counted as the first day of the menstrual cycle

2 *Proliferative phase* During this phase, the

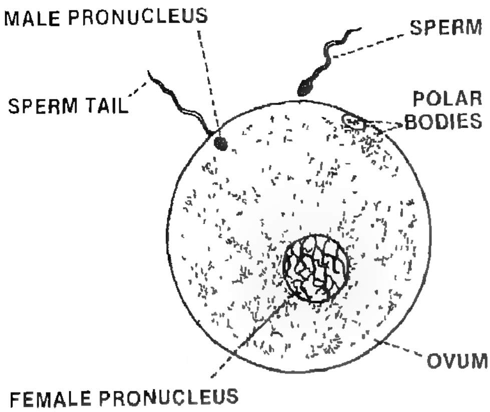


Fig 20-18 Fertilization

uterine endometrium regenerates and becomes thickened under the influence of the hormone, oestrogen. This process lasts for about 10 days and extends from 6th to 14th day of the cycle.

3 *Ovulatory phase* This normally occurs on the 14th day of the menstrual cycle and lasts for only 6 hours During this phase, an ovum is released from the Graafian follicle (ovulation) to make its entry into the Fallopian tube The body temperature also rises and remains so during the rest of the period of the cycle

4 *Luteal phase* After ovulation, the Graafian follicle is transformed into corpus luteum which secretes the hormone, progesterone As a result, the uterine glands get active and endometrium becomes more thick for the implantation of the fertilized ovum In the absence of fertilization, the menstrual cycle begins afresh

FERTILIZATION

Coitus or mating introduces the sperms into the vagina. A larger number of sperms approach the Fallopian tubes by passing through the cervix and the uterus. If an ovum is present in the tube, it can be fertilized by a single sperm, even though several of them may reach up to its surface The fusion of the two (Fig. 20-18) results in the formation of a zygote which moves down the oviduct, reaches the uterus and gets embedded in the endometrium on the 24th day of the menstrual cycle.

NUTRITION AND PROTECTION OF EMBRYO

The zygote receives almost all the cytoplasm with its reserved food material contained in the ovum. This is a good source of nutrition before implantation Subsequently, a highly vascularized structure called the placenta is formed through which the maternal blood circulates allowing the nutrients carried in it to diffuse into the embryonic blood The embryo thus starts drawing nutrition from the mother, whereas its excretory products move in the reverse direction by the process of diffusion Surrounding the embryo is a cavity called the amnion that is filled with a fluid It protects the growing embryo from shocks and jerks and helps in the withdrawal of the excretory products

During the third week after fertilization, the embryo is still a tiny organism of the size of a large pea. After 8 weeks, it becomes a foetus and now roughly resembles the ultimate human being. Before this time, it is difficult to determine by observation whether the embryo is that of a pig, goat, dog, monkey or man The entire pregnancy period in human females is 40 weeks after which

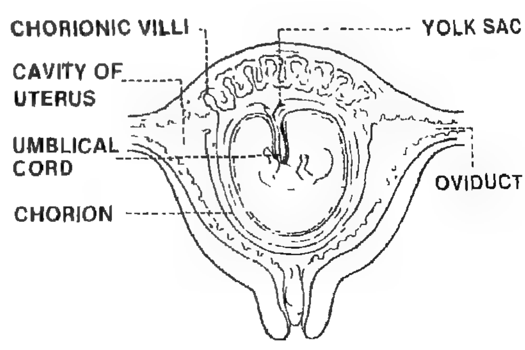


Fig 20-19 Orientation of foetus in uterus

the process of expulsion of the foetus from the uterine lumen (parturition) begins thus terminating the pregnancy. The orientation of the foetus in the womb is shown in Fig 20-19 The birth of the child is brought about by the process called labour which involves rhythmic contractions and propulsion movements of the uterus, generally accompanied by severe pains known as labour pains The cervix becomes soft and dilates The uterine contractions push the foetus down into the genital passage Generally the head comes out first The labour continues until the entire placenta is also expelled out

Some Useful Terms

Acrosomal Cap Structure at the anterior end of a spermatozoan which reacts with the egg surface during fertilization

Adventitious Bud Any bud located at other than the axil of a leaf or a branch

Antheridium A male-gamete-producing organ of a gametophyte

Archegonium A flask-shaped female-gamete-producing organ of a gametophyte

Archegoniophore A branch on the thallus bearing archegonia

Bartholin's Glands Glands occurring in some mammals which lie on either side of the upper end of the vagina

Bulbo-Urethral Glands The paired glands in a mammal whose ducts open into urethra near the base of penis, Cowper's glands

Cervix Neck of the uterus, situated partly above and partly in the vagina

Clitoris A small erectile structure situated just anterior to the vaginal wall of the female mammals (homologous with the glans penis of the male)

Embryo Sac A bag-like structure in the ovule of an angiosperm, usually containing 8 cells of which the most important is the egg

Endocarp A differentiated innermost layer of the fruit wall, usually woody in nature

Exocarp The differentiated superficial layer of the fruit wall

Fallopian Tube The anterior part of the oviduct of mammals

Glans Penis A dilatation of the extremity of the mammalian penis

Gonads Primary sex organs in which male or female gametes are formed

Graafian Follicle A vesicle containing an ovum surrounded by a layer of epithelial tissue; occurs in the ovary of mammals

Heterogamete A gamete differing in size and form from the other conjugant gamete

Hypostome A conical or dome-shaped structure at the oral end of *Hydra*

Inguinal Canal A tubular opening in the lower abdominal wall containing the spermatic cord in males and uterine round ligament in females

Integument One or more coverings of the ovule having a small pore, the micropyle, forms the seed coat

Mammary Gland The milk-secreting glands of the female mammals

Megaspore A spore which gives rise to female gametophyte

Menopause A phase in woman's life when menstruation ceases

Micropyle A minute opening in the integument at the apex of the ovule through which the pollen tube usually enters

Microspore A spore which gives rise to male gametophyte

Nucellus Central tissue of ovule containing embryo sac and surrounded by integument

Oocyte An oogonium prior to the formation of the polar bodies

Oogonia The female sex organ of certain algae and fungi containing one or more eggs, cells of animal ovary which undergo repeated mitosis and eventually form oocytes

Parturition The act of bearing of the young ones in the viviparous animals

Prepuce The loose flap or skin which protects the glans penis in mammals

Progesterone One of the female sex hormones, a steroid

Prostate A gland associated with male urogenital canal which contributes substances to semen

Scrotal Sac A muscular sac containing the testes found at the posterior end of the abdomen of many mammals, scrotum

Seminiferous Tubules Numerous, minute, coiled tubes in the vertebrate testes in which sperms develop

Seminal Vesicle A sac which stores spermatozoa

Serous Membrane One of the delicate membranes of connective tissue which lines the internal cavities in the body of the vertebrates

Sertoli Cells Cells lying amongst spermatogonia to nourish them, nurse cells

Spermatocytes Cells derived from spermatogonia which undergo meiosis and eventually form the spermatids

Synergids Cells lying near the micropyle of the embryo sac, have a role in guiding the pollen tube towards the egg

Tunica Albuginea A white, dense, connective tissue surrounding the testis or ovary

Vulva The external genital opening of the female mammal

Zygospore A thick-walled resting spore formed by the union of isogametes

Things to Do

1 Cut pieces of stem, about 15 cm long, bearing a bud or a leaf, from various common plants Plant them in different kinds of soils in different kinds of conditions such as cold and humid, warm and humid, cold and dry, and warm and dry After a few days, count the number of successful rootings and compare the results

2 Study the blooms of various flowering plants from your neighbourhood Compare their sepals, petals, stamens, and carpels, Comment on the features of special interest

3 Prepare 10% sugar solution and pour it in a small shallow dish Dust some pollen grains from a ripe anther on the surface of the solution After a couple of hours, transfer some pollen grains on a glass slide with the help of a camel hair brush or a dropper Examine under microscope and make a drawing Repeat your observations at every subsequent hour

4 Request your teacher to take you to an animal farm in your neighbourhood Ask him to explain to you the methods adopted for producing better hybrid varieties Question him on the details of procedures such as storage of sperms, artificial insemination, and reasons for the failure of hybridization

5 Visit a fish farm with your teacher and understand the mode of culture and multiplication of fishes How would you classify this mode of reproduction?

6 Make labelled drawings of the male and female reproductive organs of any mammal from a model or a dissected specimen

Test Yourself

1 Match the terms in Column I with those in Column II

Column I	*Column II*
(a) tapeworm	(i) buds
(b) *Marchantia*	(ii) rhizome
(c) *Hydra*	(iii) corn
(d) pineapple	(iv) proglottids
(e) ginger	(vi) fission
(f) *Amoeba*	(vi) gemmae
	(vii) bulbils

2 Mark the statements true (T) or false (F):

(a) Plants that reproduce asexually do not produce flowers.
(b) In reptiles the embryo grows within the womb
(c) The plant body of the gymnosperm is the sporophyte
(d) Sexual reproduction occurs by the fusion of diploid gametes
(e) In the lower plants and animals water is necessary for fertilization

3 Distinguish between.

(a) pollination and fertilization
(b) external fertilization and internal fertilization

(c) oestrous cycle and menstrual cycle
(d) spermatogenesis and oogenesis
(e) oogenesis and ovulation

4 Describe the various methods of *either* pollination *or* seed dispersal

5 Discuss the statement "During the evolution of plants there is a distinct trend in the reduction of the gametophytic stage"

6 Describe the reproductive cycle in mammals

7 How do animals take care of their eggs and young ones?

8 What is parturition? When does it take place?

9 What are Leydig cells and what is their function?

10 Describe the structure of mammalian ovary.

Try to Answer

1 What is the role of nucleus in asexual and sexual reproduction?

2 At what stages of their life cycle does meiosis or reduction division occur in *Spirogyra*, *Rhizopus*, *Marchantia*, *Pteris*, sunflower, frog and man?

3 What would happen if an organism was not to undergo asexual or sexual reproduction, but continue living permanently as such?

4 In winter, why does it take longer to make curd?

5 Enumerate the benefits, if any, of propagation of plants through seeds

6 What are the advantages of an effective fruit or seed dispersal mechanism to a plant?

7 Why is it considered better to grow a rose from cuttings rather than from seeds?

8 What is the minimum number of meiotic divisions necessary for production of 100 seeds in a flowering plant?

9 Use of insecticides is causing disappearance of some orchids How?

10 Sea coasts are usually lined by coconut trees Why?

11 Why does the scrotum of the testes contract after cold-bath and become more relaxed during a sauna bath? What is its biological significance?

12 List the male and the female hormone-producing glands and their functions in human male and female.

13 Compare the size of the gametes and gamete-producing organs of human male and female

14 How much time does it take for the sperms to travel from the lower part of the uterus to the egg? What difficulties do they encounter on the way?

15 State the effect of maternal diet, smoking and drinking on the growth and development of the foetus

16 What are the advantages of breast feeding over bottle feeding? How does breast feeding affect the child and the mother?

17 A couple is childless even after five years of their marriage What possible causes can you attribute to such a situation?

18 How soon can a woman conceive after childbirth?

19 How do fibroids develop in place of embryos in the womb o... ...n?

20 What are test tube babies? What are the hazards in producing them?

21 Compare and contrast the life cycle of an angiosperm with that of a mammal

22 Which common features of reproduction of flowering plants and mammals are responsible for their success?

23 Is there any similarity between a bird's egg and a seeded fruit of a plant?

24 In your opinion which modes of reproduction in plants and animals are of the primitive type, and which are most advanced?

25 Why are males reproductively active throughout their life span but not the females?

26 Even though one sperm is enough to fertilize an ovum, why does the ejaculate contain such a large number of sperms?

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